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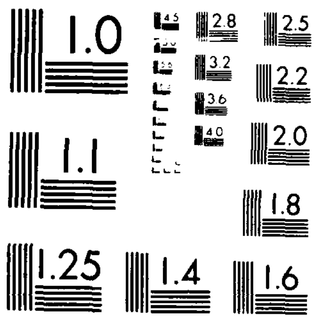

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Filtration System for Removal of Depleted Uranium from Water

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AD-A195 655

FEBRUARY 1988

FINAL REPORT FOR PERIOD JUNE-DECEMBER 1987

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AIR FORCE ARMAMENT LABORATORY
Air Force Systems Command ■ United States Air Force ■ Eglin Air Force Base, Florida

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FOR THE COMMANDER

Joe A. Farmer

JOE A. FARMER
Chief, Operations Division

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Previous depleted uranium (DU) munitions testing at Eglin AFB has resulted in 500 to 35,000 gallons of wastewater containing:

a. DU concentrations from 2.5×10^{-5} to 9×10^{-8} microcuries/mL
b. DU particles equal to and greater than 0.1 micron in size.

Eglin personnel reasoned that if particles could be filtered from the wastewater down to a 0.1 micron size, the wastewater could be disposed of on-site and comply with the Nuclear Regulatory Commission (NRC) standard of 35 pCi/g of soil.

The objective of the program was to compare the effectiveness of three cross-flow membrane modules using a pilot-scale microfiltration system that was: (1) designed to process the wastewater described above, and (2) designed to allow direct scale-up to a system that is capable of processing 35,000 gallons of wastewater that can then be disposed of on-site within applicable standards.

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The three membrane modules tested were:

A/G Technology #CFP-1-E-55, 0.1 micron pore size
ENKA #MD080TP2N, 0.2 micron pore size
ALCOA Membralox #1P19-40, 0.1 micron pore size.

All three modules were approximately the same cost.

The A/G module was observed to have the best permeate flux at low pressure and the best recovery of DU due to its 0.1 micron pore size.

PREFACE

This report describes a contract effort by TTI Engineering, 333 Providence Highway, Norwood, Massachusetts 02062. The work was performed for the Air Force Armament Laboratory (AFATL/DOE), Eglin Air Force Base, Florida 32542-5434, under Contract No. F08635-87-C-0035 during the period 11 June to 31 December 1987. The work was directed by Paul T. Bartlett, Project Manager, of TTI. Ms. Suzanne Wolfe, Physical Scientist, was the Technical Officer from AFATL/DOE for the project.

TTI wishes to acknowledge the cooperation of Nuclear Metals Inc. (NMI) of Concord, Massachusetts, in providing a test site and analytical support, and the Environics Branch staff at Eglin AFB for their analytical support during the program.

The report compares the effectiveness of three cross-flow membrane modules used in a pilot-scale, microfiltration system for removing depleted uranium (DU) particles from water.

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SECTION I
INTRODUCTION

Previous depleted uranium (DU) munitions testing at Eglin AFB, Florida, has resulted in the generation of 500 to 35,000 gallons of wastewater containing:

a. DU concentrations from 2.5×10^{-5} to 9×10^{-8} microcuries/mL.

b. DU particles equal to and greater than 0.1 microns in size.

Onsite disposal of wastewater must comply with the 10CFR20 standard of 40 pCi/cc of water and the Nuclear Regulatory Commission (NRC) standard of 35 pCi/g of soil. Onsite disposal of the above cited wastewater will violate the standards.

The Air Force Armament Laboratory, Environics Branch (AFATL/DOE) contracted TTI Engineering to supply a "Filtration System for Removal of Depleted Uranium From Water" to treat the type wastewater described above to radioactivity levels that will allow onsite disposal in compliance with applicable standards.

TTI Engineering fabricated and tested a pilot-scale microfiltration system for AFATL/DOE to compare the effectiveness of three cross-flow membrane modules for removal of depleted uranium and DU compounds from water. The pilot system was designed to allow direct scale-up to an onsite system that will be capable of treating 500 to 35,000 gallons of the wastewater described above.

All particles greater than 0.1 microns in size were to be removed by the microfilter in the pilot system. Particle filtration to this level should control radioactivity and satisfy the above standards if onsite disposal only occurs once.

TTI performed the tests at Nuclear Metals, Inc. (NMI), in Concord, Massachusetts. The DU water stream experienced and/or anticipated at Eglin AFB was replicated by NMI for content and particle size. This stream was then fed to the filtration system for treatment.

This report discusses the membrane module systems that were evaluated, the methods that were used for the performance tests, and the test results. Conclusions and recommendations based on these tests are also presented.

SECTION II
TECHNICAL DISCUSSION

2.1 System Description

Pilot-scale tests were performed using the test system shown by Figures 1a and 1b and the drawings of Appendix A. The system was designed to allow testing of three cross-flow membrane modules to compare performance and evaluate optimum operating conditions. The three modules tested were:

A/G Technology #CFP-1-E-55, 0.1 micron pore size
ENKA #MD080TP2N, 0.2 micron pore size
ALCOA Membralox #1P19-40, 0.1 micron pore size.

The design basis used for this system was determined from the conditions provided by Eglin AFB on the stream encountered from DU munitions underwater testing. The system was designed to remove particles greater than 0.1 micron in size, and in the 2.5×10^{-5} to 9.0×10^{-8} microcuries per milliliter radioactivity level range.

The replicated feed stream provided by NMI was made by adding 8 pounds of pure U_3O_8 to 55 gallons of well water from the plant property in Concord, Massachusetts. The mixture sat for several days allowing large particles to settle. Water from the top of the 55-gallon barrel was then batch loaded into the test system's feed tank for processing.

The system was designed to operate at ambient temperatures, and with feed pressures varying up to 80 psig.

The system feed flow rate can be adjusted up to approximately 15 gallons per minute, depending on the feed pressure and recirculation rate.

The material of construction for the pilot system was polyvinyl chloride (PVC). This material was chosen for its low cost, light weight, and corrosion resistant properties under the test conditions. The system was sized to be portable and conveniently moved on a standard bed truck. The overall system dimensions are 32.0" wide by 79.3" long by 74.4" high with an angle iron frame to support the system.

2.2 Description of System Operation

Figure 1a presents the system process flow diagram. The feed is batch loaded into the feed tank. From there it is pumped by the feed (gear) pump to the feed side of the membrane module. Some flow from the pump can be recirculated to the feed tank through Valve #V-2. Manipulating this recirculated flow allows adjusting the flow rate to the module. Filtered product exits the module as permeate. The permeate flows either to the permeate collection tank, or it can be diverted away from the system. The concentrated waste stream exits the module and is recycled back to the feed tank. The feed tank can then be concentrated/dewatered to the desired level.

System operation is started by opening Valve #V-2 and closing Valve #V-3, establishing flow through the recirculation loop. Valve #V-2 is slowly closed while Valve #V-3 is slowly opened to allow flow to the module. Permeate passes through Valve #V-4, Air-Operated Valve

#AOV-3, and Valve #V-5 to the permeate tank. The concentrated waste stream is returned to the feed tank through Air-Operated Valve #AOV-2 and the manual Pressure Control Valve (PCV). The PCV is used to adjust the pressure drop across the test module.

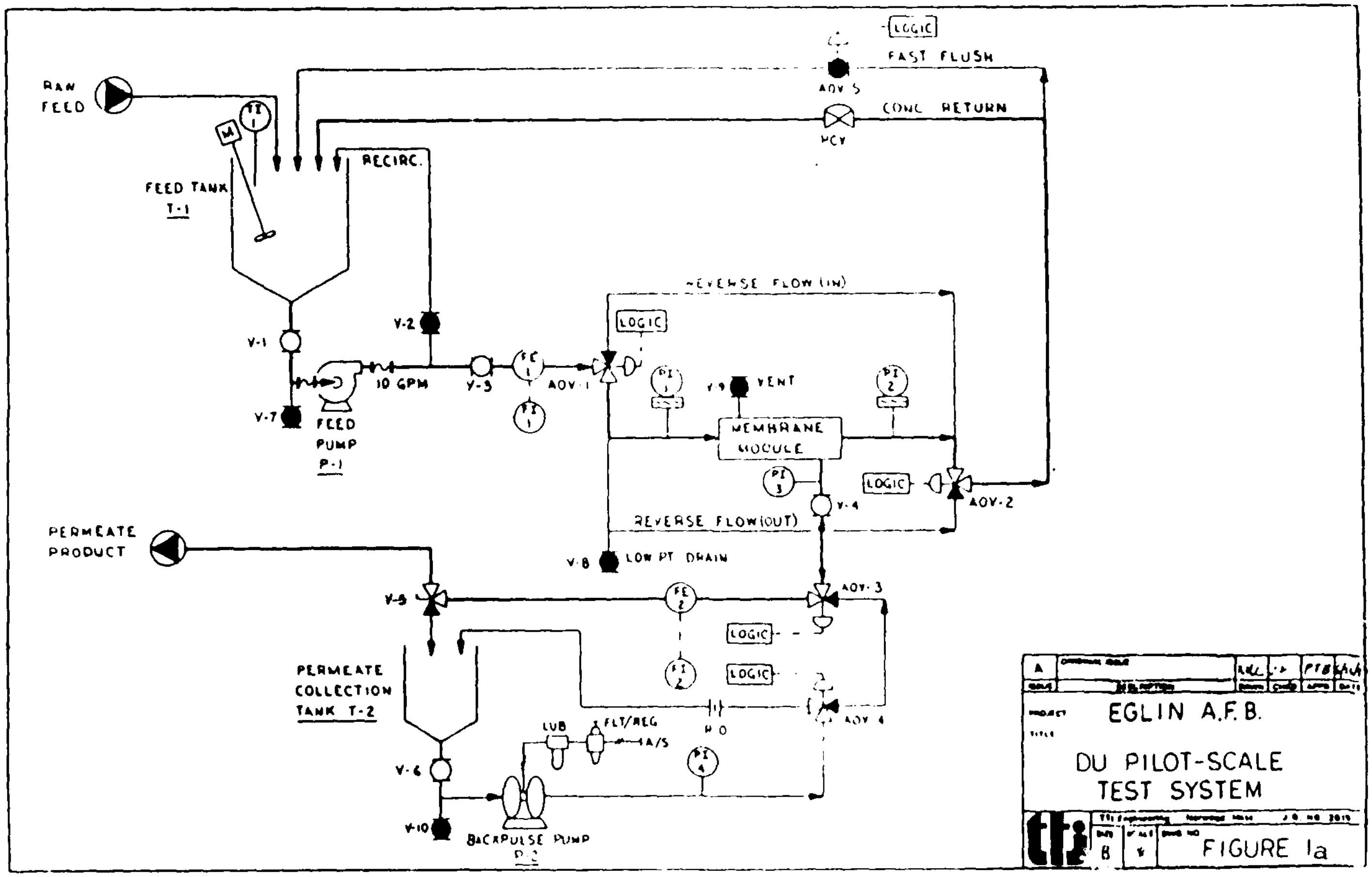


Figure 1a. Process Flow Diagram

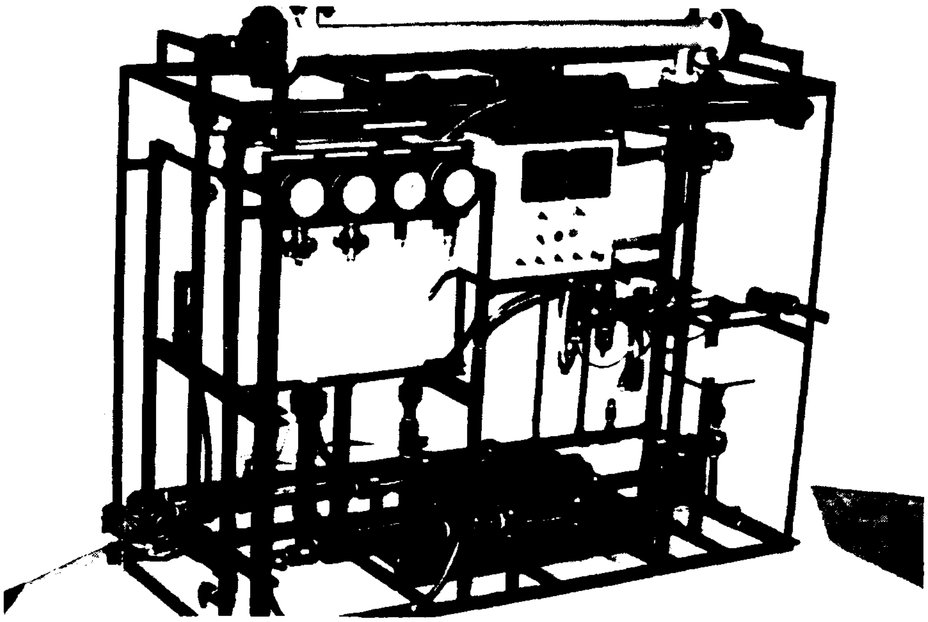


Figure 1b. Pilot-Scale Microfiltration System For Removal of Depleted Uranium From Water

Periodic, automatic, mechanical cleaning can be accomplished for all three modules. For the ENKA and ALCOA Membralox filter modules, AOV-3, AOV-4, and AOV-5 are energized. A specific amount of permeate is pumped from the permeate collection tank to the permeate side of the module. Permeate flow during this backpulse operation is in a reversed direction from normal, production flow. This action removes the solids from the walls of the membrane, and the solids are flushed from the module with the concentrate stream. Energizing AOV-5 during the backpulse operation reduces concentrate line pressure and increases concentrate velocity to provide two desirable results:

1. Fast-flushing of solids from the module occurs with the increased concentrate line velocity.

2. Backpulse pump size is reduced since pressure in the concentrate line is reduced.

For the A/G module, mechanical cleaning is accomplished by reversing the direction of concentrate flow in the module. AOV-1 and AOV-2 are energized, and the reverse flow action removes the solids from the walls of the module. Solids are then removed with the concentrate stream. Reverse flow is performed during normal operation, with permeate product still being generated.

This periodic cleaning is automatically sequenced from a programmable logic controller. Backpulsing is usually performed for 2 to 3 seconds every 3 to 5 minutes. Reverse flow is usually performed for 5 to 10 seconds every 5 to 10 minutes.

During normal operation, the following process parameters can be monitored from the control panel:

1. Feed flow rate
2. Permeate flow rate
3. Feed pressure at inlet to filter module
4. Concentrate pressure at outlet to filter module
5. Permeate pressure
6. Backpulse pressure.

From the control panel, air-operated valves can be energized or de-energized, the feed pump can be stopped or started, and a mechanical cleaning sequence can be initiated manually. There is also the capability for alternating between the two types of mechanical cleaning, depending on the type of module being used in the system. All automatic controls can be overridden from the control panel by placing the system in a manual mode.

2.3 Test Method and Procedure

Tests were performed with the three modules to compare flux performance and removal efficiencies using the test procedure found in Appendix B. For each of the three modules, the following general procedure was used:

Approximately 20 gallons of feed were batch loaded into the feed tank. The system was started, beginning with recirculating all of the feed back to the feed tank to fully mix the feed. Then, a feed sample was taken for analysis. Starting with low feed flow rates and low transmembrane pressure drops[1], feed was introduced into the filter modules. The process parameters were recorded as the flow rate and pressure drop were increased. A permeate sample was taken during normal operation, noting the time of the sample on the sample bottle. When the feed tank had been dewatered to approximately five gallons, the test was stopped, and a concentrate sample was taken from the feed tank. Fifteen hundred milliliters of each sample were taken for analysis.

From the 1500-mL sample, a 500-mL sample was given to NMI, AFATL/DOE, and Carolina Metals, Inc. (CMI) for chemical analysis. This set of tests was to determine the removal efficiency for each of the modules. Analysis of the samples determined the solids content, particle size, and radiation level for the feed, concentrate, and permeate samples taken for each of the modules.

After the removal efficiency tests were performed, the system was modified slightly to allow for constant recycling of the concentrate and permeate streams back to the feed tank. This recirculation maintained a constant solids content in the feed tank. With this configuration, the operating conditions for each of the modules were optimized. The objective was to locate the optimum operating conditions for the module during constant operation, so the feed flow rate was kept as high as possible for the pressure being used. The concentrate

[1] Transmembrane dP = (feed pressure + concentrate pressure)/2 - permeate pressure

backpressure was varied, while measuring the flux through the module and the other process parameters. The feed pressure was varied from zero to the highest recommended operating pressure for each module. The feed flow rate varied (decreased) with the increase in pressure.

In addition to the flux optimization tests, flux degradation tests were also performed. Using an intermediate pressure and the highest maintainable flow rate, the system was operated without adjusting valves or pumps. Data were taken every 5 minutes for 1 hour to determine if there were any adverse effects of long-term operation. Examples of this degradation can be seen as a decrease in permeate flow rate or an increase in concentrate pressure, indicating fouling of the membrane module.

SECTION III
RESULTS AND DISCUSSION

3.1 Flux Performance Results

Flux performance tests were performed on the three modules using a replicated waste stream at NMI in Concord, Massachusetts. The data from these tests are shown in Figures 2 and 3 and Tables 1, 2, and 3. As can be seen from the two plots, the flux rate generally increased with increasing transmembrane pressure drop (dP).

Figure 2 shows the flux in gallons per minute for the module, not accounting for the actual surface area of the membrane. The ENKA #MD080TP2N with a 0.2 micron pore size exhibited the highest flux rate of 9.2 gallons per minute (gpm) permeate with a feed rate of 10.7 gpm at a transmembrane dP of 26 pounds per square inch of gauge pressure (psig). This appears to be the optimum operating transmembrane dP for this module. However, the flux rate for this module is strongly dependent on the transmembrane pressure drop. A small decrease in transmembrane dP causes a comparatively large decrease in permeate flux rate.

The A/G Technology module #CFP-1-E-55 (0.1 micron pore size) also exhibited a high flux rate. The optimum operating transmembrane dP seemed to be approximately 20 psig, resulting in a permeate flow rate of 6.3 gpm with a 13-gpm feed rate. This feed to permeate flow rate ratio of 2 to 1 is much higher than that for the ENKA module of 1.2 to 1. There is a much larger required recycle rate for the A/G module than for the ENKA module, therefore requiring a larger feed pump to accomplish the same permeate flow rate.

The Membralox #1P19-40 (0.1 micron pore size) module exhibited the lowest permeate flow rate for the range of transmembrane dPs tested. This module showed no optimum operating condition in the range of conditions tested. It did, however, achieve a permeate flow rate of 6.8 gpm with an 8 gpm feed rate. The feed to permeate ratio of 1.2 to 1 is very attractive, but this ratio requires a high transmembrane pressure drop of 60 psig.

Figure 3 compares the flux rates for the three modules on a per square foot of membrane surface area basis. By this comparison, the Membralox membrane appears to have the greatest flux rate, followed by the ENKA and then the A/G Technology module. This is the basis normally used to compare filter flux rates. However, in this case where we are concerned with achieving the highest permeate flow rate for the least cost, the results of Figure 3 can be misleading, and lead to a less attractive choice of membrane.

Since the three modules have approximately the same cost, the absolute permeate flux rate, not the surface area per module, is the property which needs to be considered for comparison.

The difference between the results shown in the two figures is due to the relatively large surface area per module of both the A/G Technology and ENKA modules, 23 and 10.8 ft^2 respectively. In comparison, the Membralox module has only 2.1 ft^2 of membrane surface area.

Flux degradation tests resulted in no change in flux or pressure for the hour of testing for the Membralox or the ENKA modules. The A/G Technology module exhibited an increase in pressure on the feed side of the module. However, the automatic mechanical cleaning restored the pressure to its original value, and no decrease in permeate flow was noted.

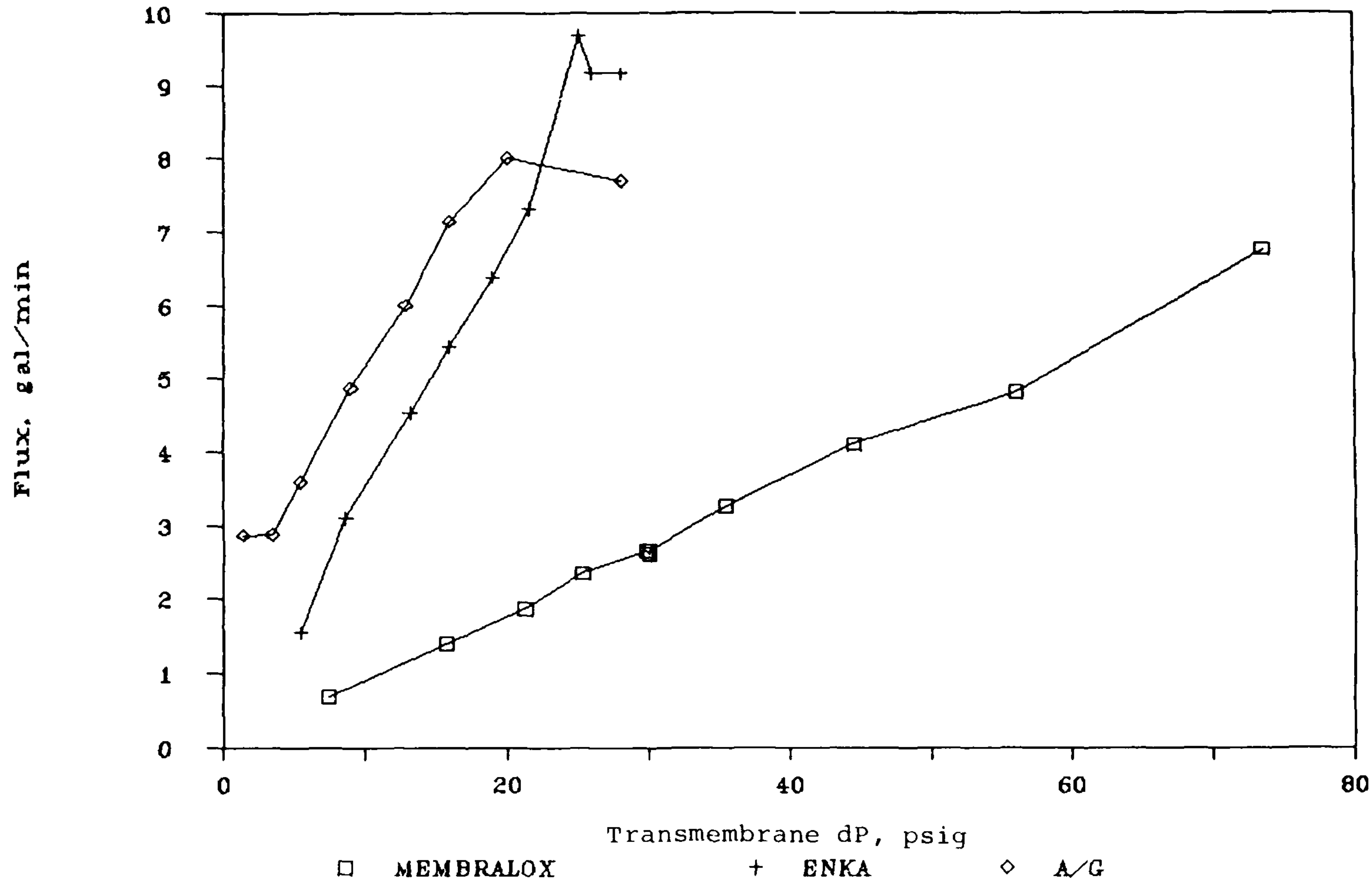


Figure 2. Flux Performance Data

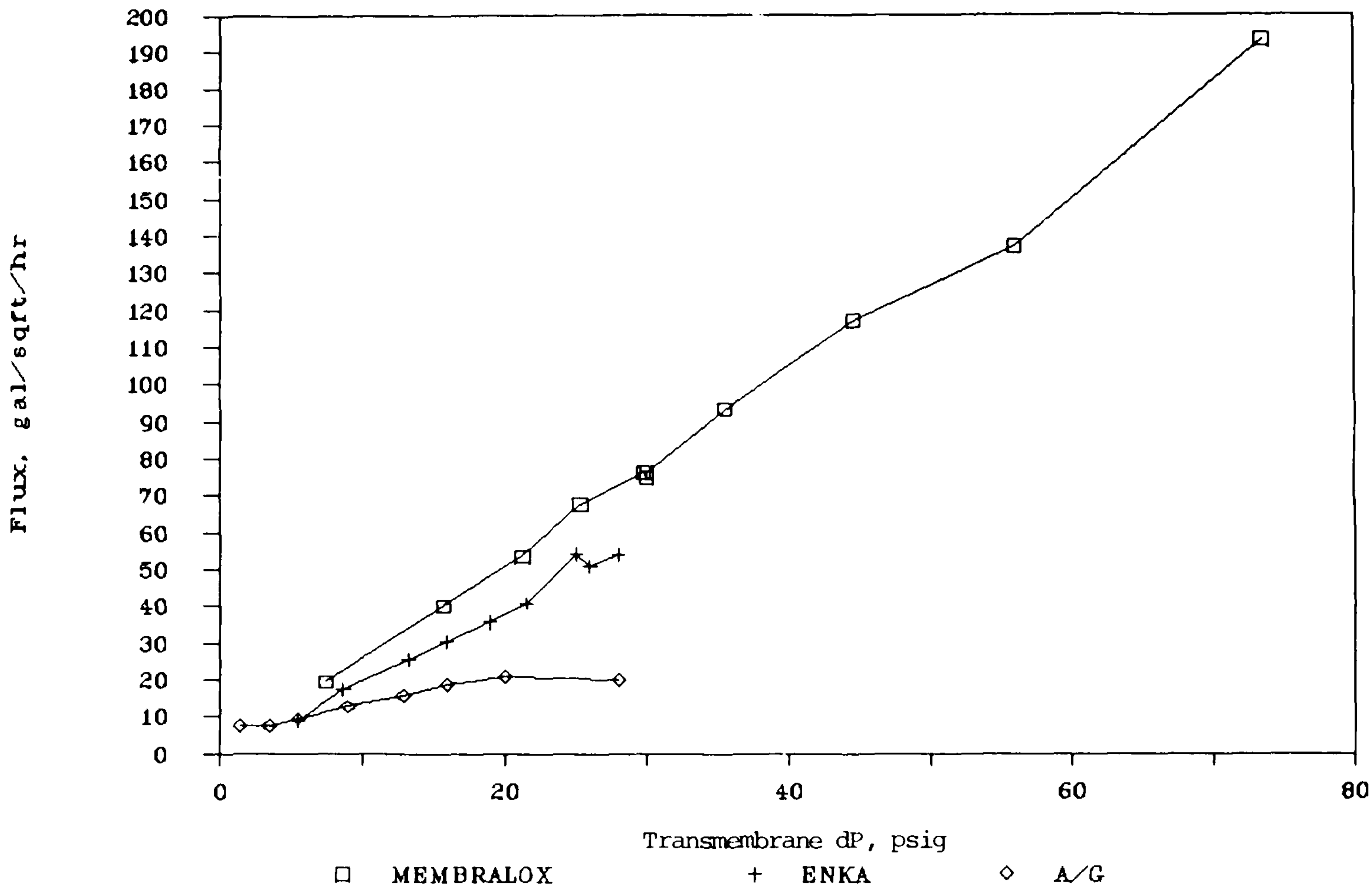


Figure 3. Flux Performance Data on an Area Basis

TABLE 1. FLUX DATA FOR ENKA #MD080TP2N MODULE

Feed Flowrate gpm	Permeate Flowrate gpm	Permeate Flux gal/sq.ft./hr	Transmembrane Pressure Drop psig
14.00	1.55	8.64	5.50
14.00	3.11	17.34	8.70
13.20	4.54	25.32	13.25
12.50	5.43	30.28	16.00
12.00	6.38	35.58	19.00
11.50	7.32	40.82	21.50
11.20	9.68	53.98	25.00
10.70	9.16	51.08	26.00
10.70	9.68	53.98	28.00

TABLE 2. FLUX DATA FOR MEMBRALOX #1P19-40 MODULE

Feed Flowrate gpm	Permeate Flowrate gpm	Permeate Flux gal/sq.ft./hr	Transmembrane Pressure Drop psig
14.00	0.68	19.43	7.50
13.00	1.40	40.00	15.75
12.50	1.87	53.43	21.25
12.00	2.36	67.43	25.30
11.50	2.66	76.00	29.75
11.50	2.61	74.57	30.00
11.50	2.66	76.00	30.00
11.00	3.26	93.14	35.30
10.20	4.10	117.14	44.50
9.50	4.80	137.14	56.00
8.00	6.76	193.14	73.50

TABLE 3. FLUX DATA FOR A/G TECHNOLOGY #CFP-1-E-55 MODULE

Feed Flowrate gpm	Permeate Flowrate gpm	Permeate Flux gal/sq.ft./hr	Transmembrane Pressure Drop psig
15.00	2.87	7.49	0.17
14.70	2.88	7.51	3.50
14.50	3.60	9.39	5.50
13.70	4.87	12.70	9.05
13.00	6.00	15.65	12.90
12.50	7.14	18.63	16.00
30.00	8.00	20.87	20.00
36.00	7.69	20.06	28.00

3.2 Chemical Analyses

3.2.1 Radioactive Solids Content Analysis

Various chemical analyses were performed to determine the amount of solids and the radiation levels due to the uranium in the various samples. Samples were given to Eglin AFB (AFATL/DOE), NMI, and CMI for independent analysis. The three organizations employed the following analytical methods to determine radioactivity levels:

CMI - Inductively Coupled Plasma Spectroscopy (ICP)

NMI - alpha and gamma radiation counting: gamma by Nuclear Data #ND6 Analyzer, alpha by proportional counter of aliquot of sample onto Millipore filter

AFATL/DOE - low background alpha and beta counter; reported beta. Particle size analysis by scanning electron microscope.

Appendix D presents the analytical results received from the three laboratories. NMI presented their results with a comparison to CMI results. The Eglin results are presented with a comparison to both NMI and CMI results.

In all cases, the radiation levels by count were converted from picocuries per milliliter (pCi/mL) to a solids concentration in parts per million (ppm), based on U_3O_8 being the prevalent solid in the replicated wastewater. General results from these tests are given below. Since the three laboratories generated three different sets of results, the results will be shown separately, and then compared to each other.

AFATL/DOE results are listed in Tables 4 and 5. There was some difficulty in performing the tests because the majority of the solids adhered to the walls of the sample bottles. Multiple rinsings and dilutions were performed in order to remove the samples from the bottles. This problem may have some effect on the results that were reported for the radiation levels.

As can be seen in Table 4, the radiation levels of the feed varied between 6.3 and 10.0 pCi/mL, indicating a uranium content of between 17,400 and 27,200 ug/L. These results indicate that the feed was in fact representative of the stream that was desired and that was expected by and encountered at Eglin AFB during munitions testing.

The permeate radiation levels were measured at between 4.1 and 7.3 pCi/mL, indicating a uranium level of between 11,400 and 20,300 ug/L. These results show a significant uranium removal using the three membrane modules. The

A/G Technology and the Membralox membrane modules both yielded a 34 percent removal based on the feed and permeate concentrations. The ENKA module yielded a 27 percent removal.

NMI results listed in Table 5 are the average of the gamma and alpha radiation level measurements, and they show that the feed concentration was between 5,800 and 15,300 ug/L. These results are lower than those reported by AFATL/DOE, probably as a result of the adhesion of solids to the walls of the sample bottles. Failure to remove all of the adhered solids will result in a lower measured solids content.

NMI reported results show similar solids removal efficiencies as were reported by AFATL/DOE. By averaging the gamma and alpha radiation results for each of the samples, the following removal percentages were calculated. The Membralox module yielded the highest percentage removal of 52 percent, followed by the A/G Technology module with a 48 percent removal. It should be noted, however, that the concentration of the feed to the A/G Technology module (15.3 ppm) was significantly higher than that to the Membralox module (9.2 ppm), and this may have some effect on the percentage removal reported for the two modules. No removal percentage can be reported for the ENKA module in this case, since the concentration of the feed sample was measured as lower than the concentration of the permeate sample. This probably indicates a problem with measuring the actual concentration of the samples, and a lower solids removal efficiency of the ENKA module due to its 0.2 micron pore size.

The final set of solids concentration data were reported by CMI, based on Inductively Coupled Plasma Spectroscopy. This analysis was performed using three techniques which resulted in three sets of results. The first set of tests were performed by concentrating the sample in 10 percent nitric acid. These results showed little variation in concentration between the concentrate and permeate streams. Based on the results reported by both AFATL/DOE and NMI, it was determined that these results were not valid. It appeared that by using nitric acid as the carrier fluid for the samples, solids that were not dissolved in the water dissolved in the acid, thereby changing the composition of the streams, i.e., by dissolving suspended solids.

CMI then reran the tests using water as the carrier fluid. This yielded results less consistent with those reported by NMI and AFATL/DOE; the concentrations were much lower than expected. Finally, the tests were run using nitric acid as the carrier fluid, but after rinsing the walls of the sample bottles with nitric acid. It appears that the nitric acid method was appropriate, but that much of the solids had adhered to the walls of the sample bottles, thus leading to inaccurate results in the first set of tests.

Therefore, based only on the last set of results, CMI tests resulted in the following removal efficiencies. The Membralox module yielded 31 percent removal, followed by the A/G Technology module with a 22 percent removal. Again, the ENKA module yielded the lowest efficiency with a 16 percent removal.

3.2.2 Particle Size Analysis

Particle size analysis was performed only by AFATL/DOE at Eglin AFB using Scanning Electron Microscopy (SEM). The results of these tests are qualitative rather than quantitative. Feed samples were prefiltered through a 0.22 micron Millipore filter. Feed samples were examined with the SEM and particles were measured at greater than 0.5 microns in size. The particle sizes seen in the feed stream seem to represent those seen in the water encountered at Eglin AFB after munitions underwater testing.

Permeate samples were prefiltered through 0.22 micron filter paper. No particles were held on the paper, and all particles measured on the SEM were smaller than 0.2 microns. AFATL/DOE also reported that the A/G Technology module seemed to have done the best job of removing particles from the feed stream.

Concentrate samples were not examined for particle size, since this would not yield any unique information for determining membrane performance.

TABLE 4. RADIATION CONCENTRATION RESULTS

Sample	AFATL/DOE[1] pCi/mL	CMI[2] pCi/mL
ENKA Feed	9.97	4.9
ENKA Permeate	7.31	4.1
ENKA Concentrate	4.47	4.3
A/G Feed	9.55	5.8
A/G Permeate	6.26	4.5
A/G Concentrate	19.46	10.2
Membralox Feed	6.26	3.9
Membralox Permeate	4.09	4.5
Membralox Concentrate	5.10	10.2

1 AFATL/DOE analysis by low background alpha and beta counter; beta values are reported.

2 CMI analysis by Inductively Coupled Plasma Spectroscopy (ICP).

TABLE 5. SOLIDS CONCENTRATION RESULTS

Sample	AFATL/DOE[1] ppm	CMI[1] ppm	NMI[1,2] ppm
ENKA Feed	27.2	13.7	5.84
ENKA Permeate	20.3	11.5	10.25
ENKA Concentrate	12.4	12.0	7.48
A/G Feed	26.5	16.2	15.30
A/G Permeate	17.4	12.6	7.99
A/G Concentrate	54.0	28.4	25.80
Membralox Feed	17.4	10.7	9.21
Membralox Permeate	11.4	7.4	7.99
Membralox Concentrate	14.2	15.8	25.80

1 Values in ppm are calculated from radioactivity count based on U_3O_8 being prevalent solid in sample.

2 NMI analysis by alpha and beta counting - gamma by Nuclear Data #ND6 analyzer and alpha by proportional counter of aliquot of sample onto Millipore filter. Average of alpha and gamma then used to calculate concentration in ppm.

SECTION IV

CONCLUSIONS

4.1 Flux Performance Tests

The A/G Technology and ENKA modules exhibited the best flux performance over the range of conditions tested. The Membralox module performance cannot be considered competitive with the other two modules.

The ENKA and Membralox modules demonstrated no decrease in flux performance over a 1-hour time period while automatic mechanical cleaning was being periodically performed. The A/G Technology module did exhibit increased pressure during these tests. No detrimental effect was noticed in the permeate flow rate. Increasing the frequency of the reverse flow mechanical cleaning will probably eliminate the pressure increase noticed during the A/G tests.

4.2 Chemical Analyses

The A/G Technology and Membralox modules removed the highest percentage of solids from the feed streams tested. Since the objective was to maximize the removal of solids greater than 0.1 microns, the ENKA module cannot be considered competitive with the other two modules based on its consistently lower reported solids removal. Particles greater than 0.2 microns in size were not detected in the permeate stream for any of the three modules tested.

4.3 Overall Test Results

Based on the feed composition (suspended solids and particle size), the feed stream tested at NMI accurately represented the water stream encountered at Eglin AFB after depleted uranium munitions underwater testing. The radiation level was between 2.5×10^{-5} and 9×10^{-8} uCi/mL, and the particles were in the size range of 0.1 to 10 microns as was specified in the Scope of Work.

The solids concentration results reported in Tables 4 and 5, and the particle size analysis results reported in Section 3.2.2 demonstrate that the pilot-scale tests achieved their objective of sufficiently treating a replicated DU waste stream to allow onsite disposal in compliance with applicable standards. The microfiltration system successfully removed solids greater than 0.2 microns in size and significantly reduced radiation levels in the feed stream.

The comparison of module performance determined that for comparably-priced modules, the A/G Technology 0.1 micron unit provides the best absolute permeate flux rate at low pressure while also providing the best solids removal efficiency.

SECTION V
RECOMMENDATIONS

TTI recommends using the A/G Technology 0.1 micron module for the removal of DU from water, based on its cost-effective performance of high flux rate, high removal efficiency, and removal of all particles in the desired size range.

It is also recommended that for the onsite Eglin AFB system, the A/G Technology module be operated at a transmembrane pressure drop of approximately 20 psig, with reverse-flow mechanical cleaning automatically performed for 10 seconds every 10 minutes. For a feed rate of 13 gpm, a permeate flow rate of approximately 6.3 gpm can be expected for the 20 psig transmembrane pressure drop. An onsite Eglin AFB system, the same size as the pilot-scale system, can therefore process 35,000 gallons in less than 4 days of continuous operation.

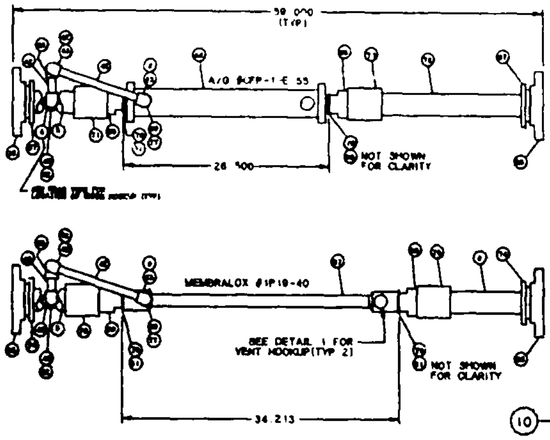
APPENDIX A

ENGINEERING DRAWINGS AND BILL OF MATERIALS

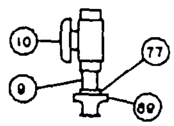
A-1	General Arrangement
A-2	Frame Arrangement
A-3	Control Panel Wiring Diagram and Electrical Block Diagram
A-4	Bill of Material

Appendix A presents TTI Engineering's Drawings that were used for fabrication and assembly of the DU filtration system. The encircled numbers on the drawings refer to the item number for the illustrated part. Refer to the Bill of Materials (B.O.M.) in this appendix for a description of the item number. The B.O.M. is categorized by component type; i.e., pump, tank, valve, etc.

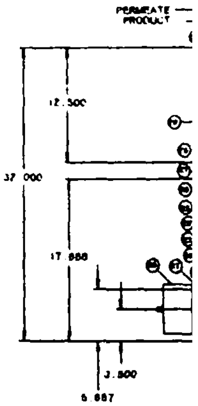
Figure A-1 presents a reduction of the E-sized overall arrangement drawing with plan and elevation (left side, rear, right side) views. Succeeding figures present only one of these views to provide better clarity.

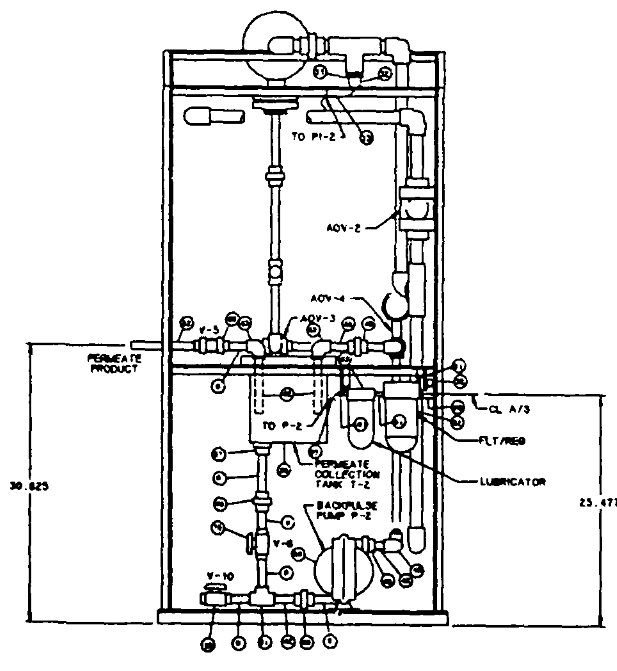


MEMBRANE ADAPTERS

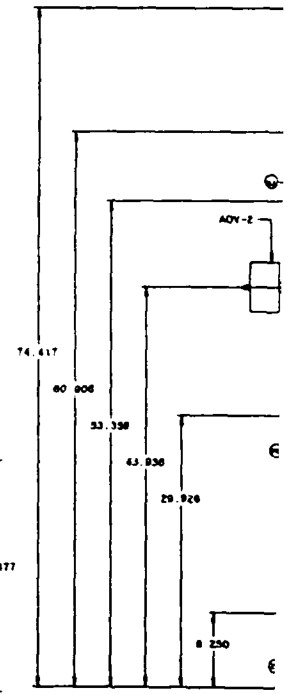


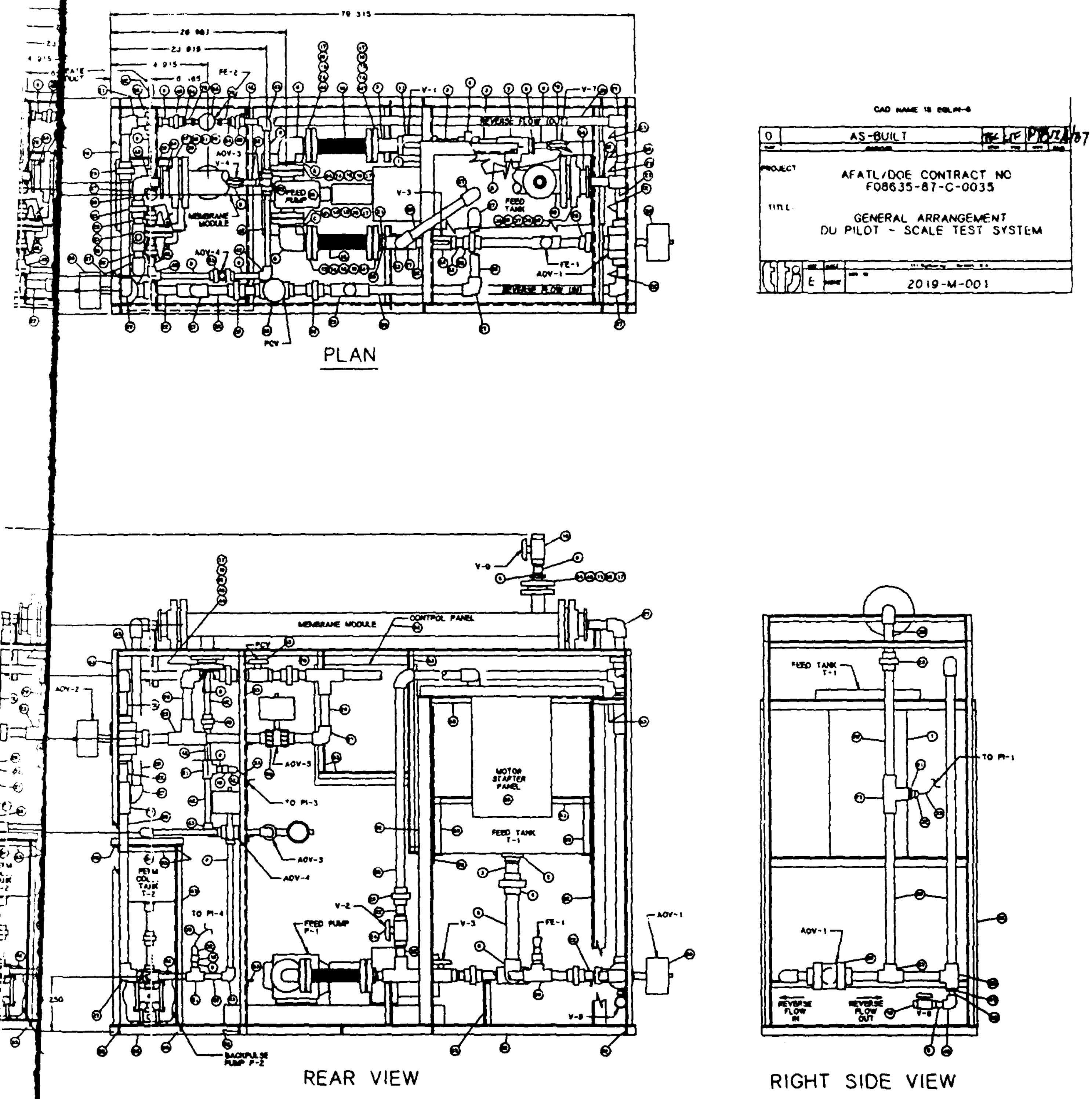
DETAIL 1





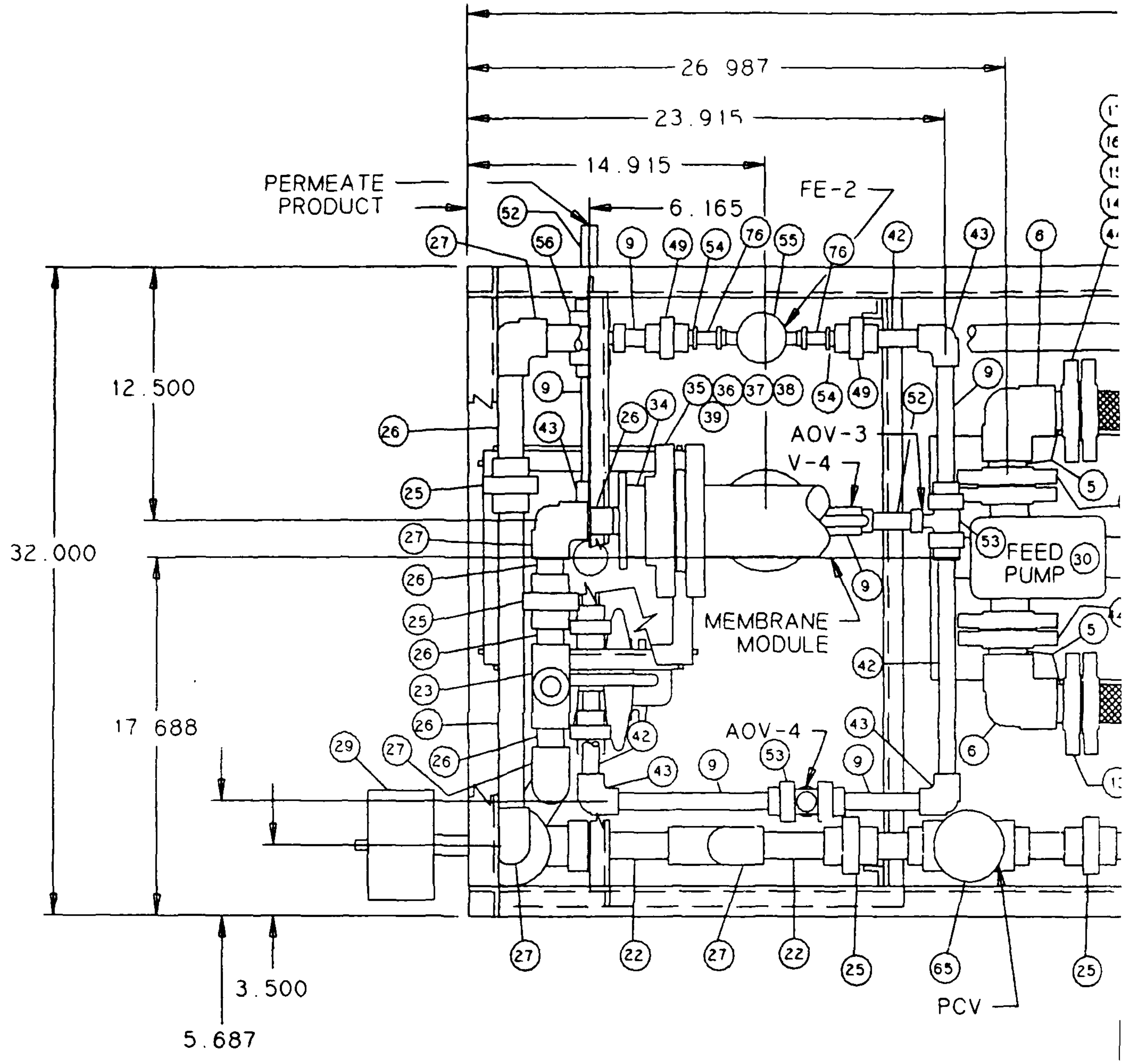
LEFT SIDE VIEW





a. Overall Layout

Figure A-1. General Arrangement



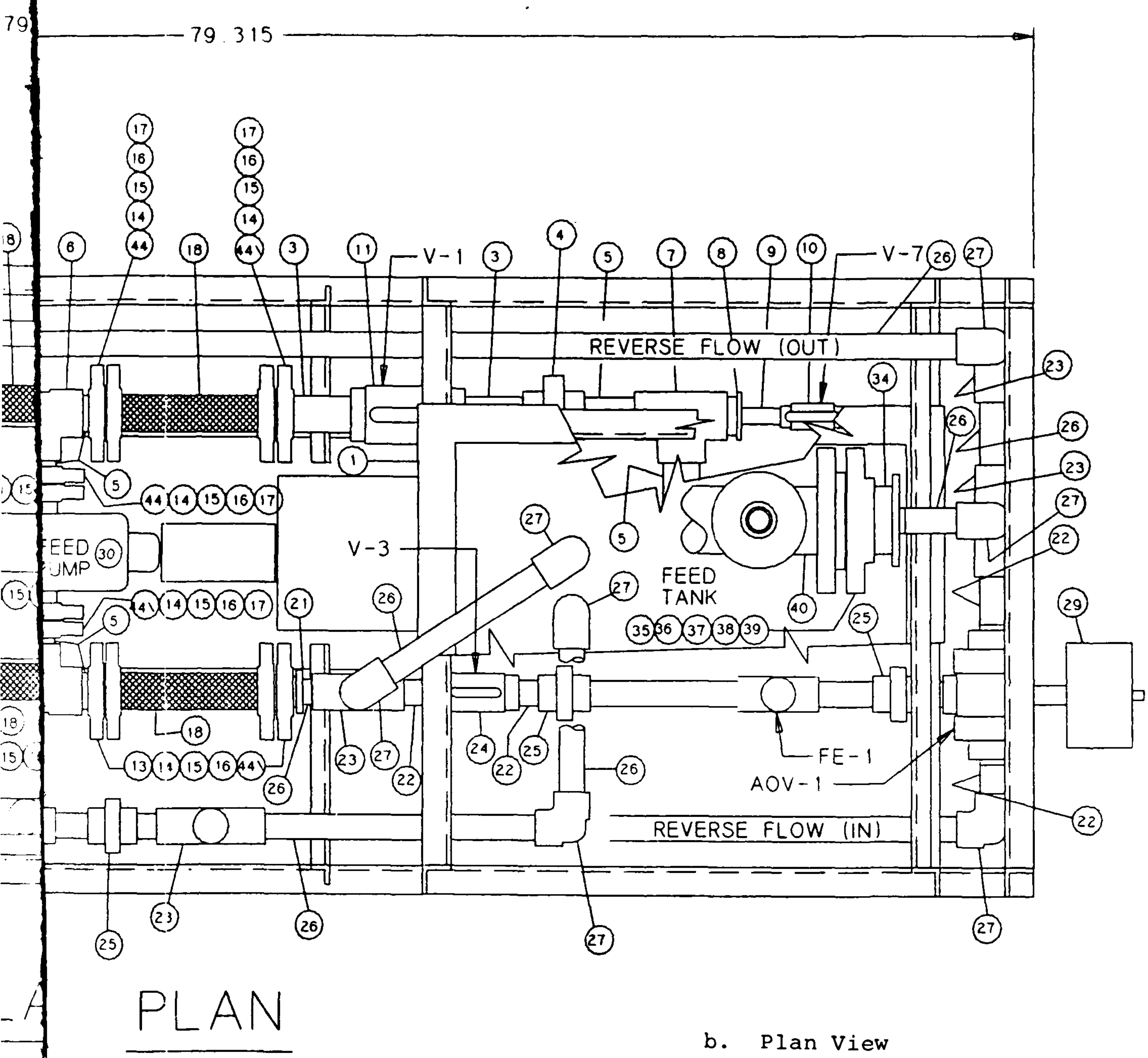
ISSUE	DESCRIPTION	DRWN	CHKD	APPR	DATE
0	AS-BUILT	TEC	LTT	FTB	12/4/87

PROJECT AFATL/DOE CONTRACT NO. F08635-87-C-0035

TITLE GENERAL ARRANGEMENT
DU PILOT - SCALE TEST SYSTEM
PLAN VIEW

TTI Engineering Norwood Ma

SIZE	SCALE	DWG. NO.
B	NONE	2019-M-001A



b. Plan View

Figure A-1. General Arrangement (Continued)

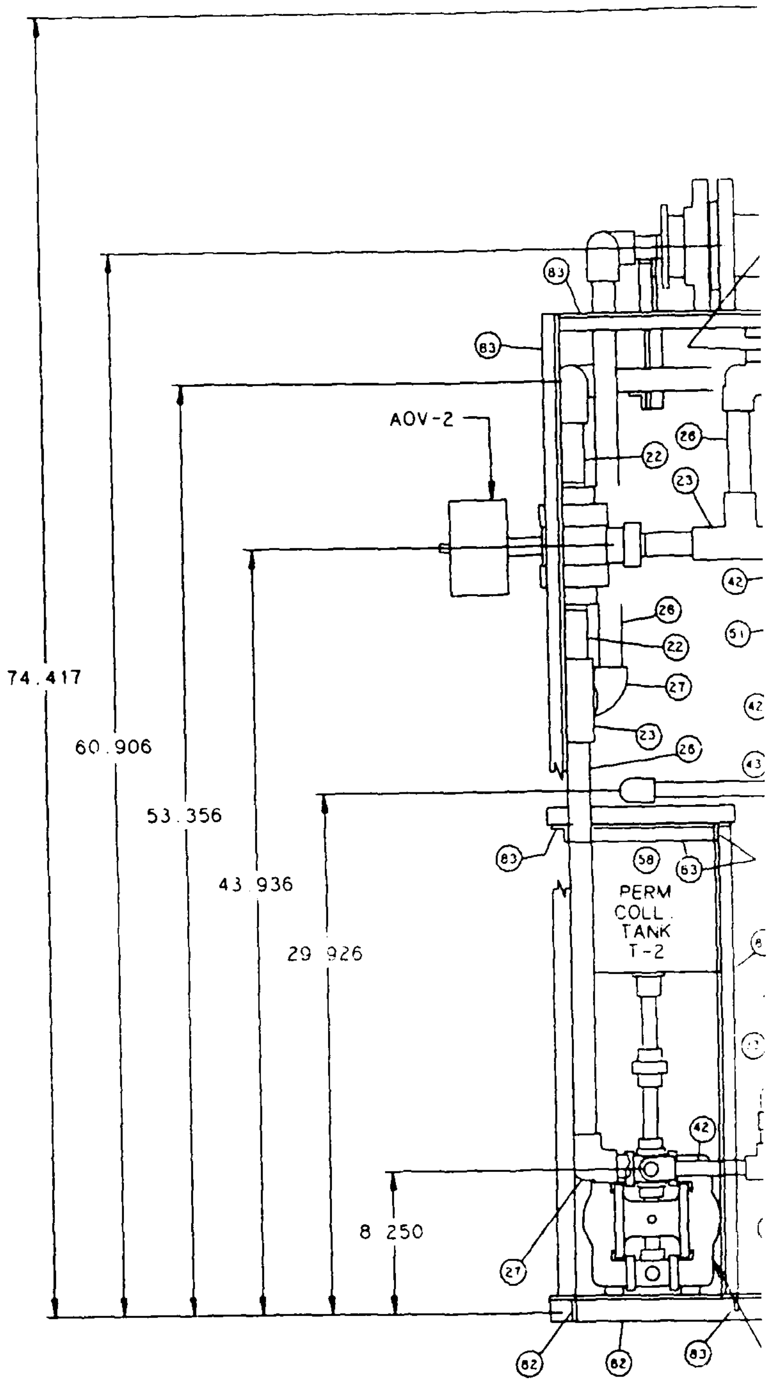
0	AS-BUILT	TEC	LTF	PTB	12/87

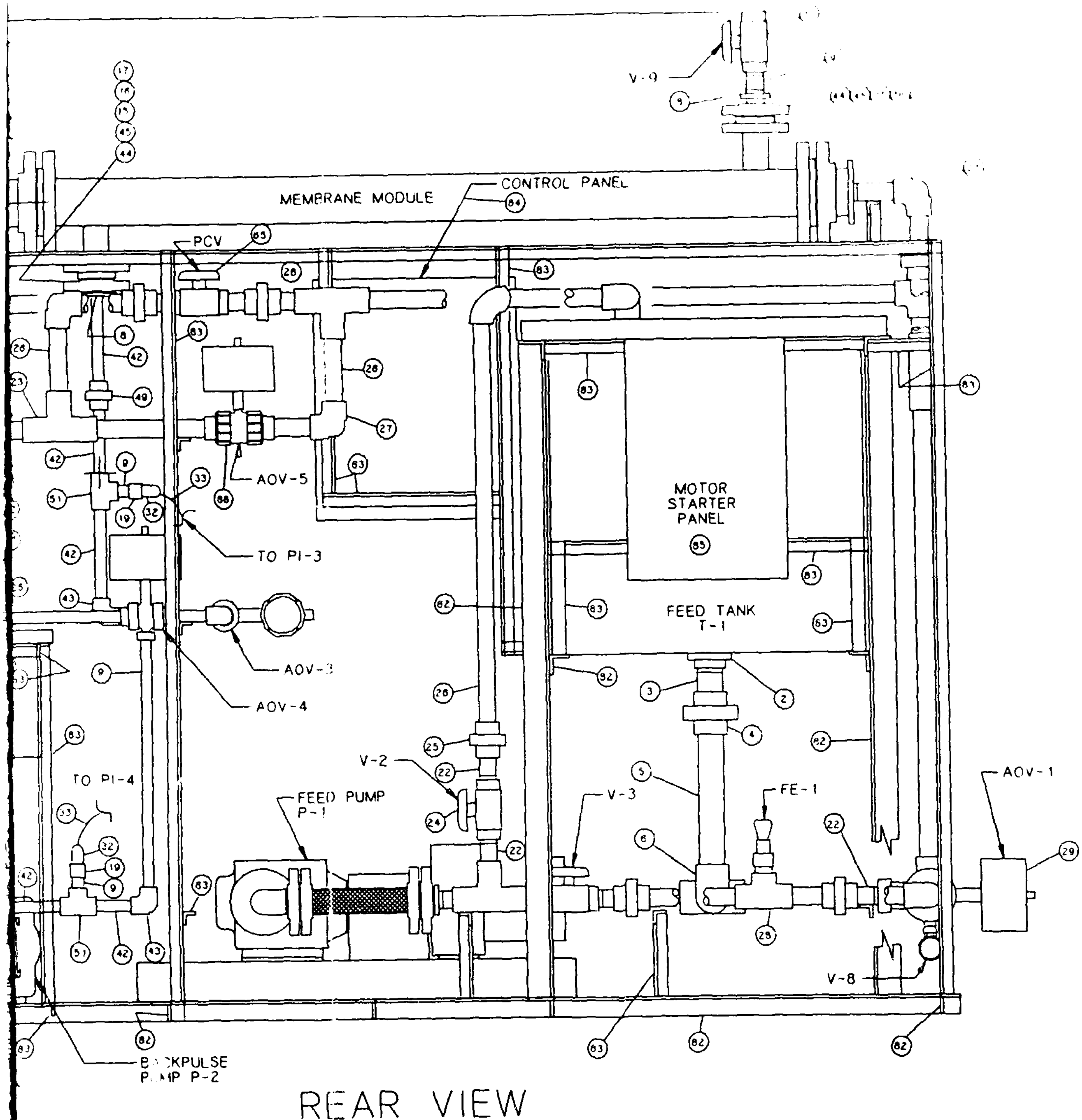
AFATL/ZONE CONTRACT NO
F08635-87-C-0295

GENERAL ARRANGEMENT
DU PILOT - SCALE TEST SYSTEM

REAR VIEW

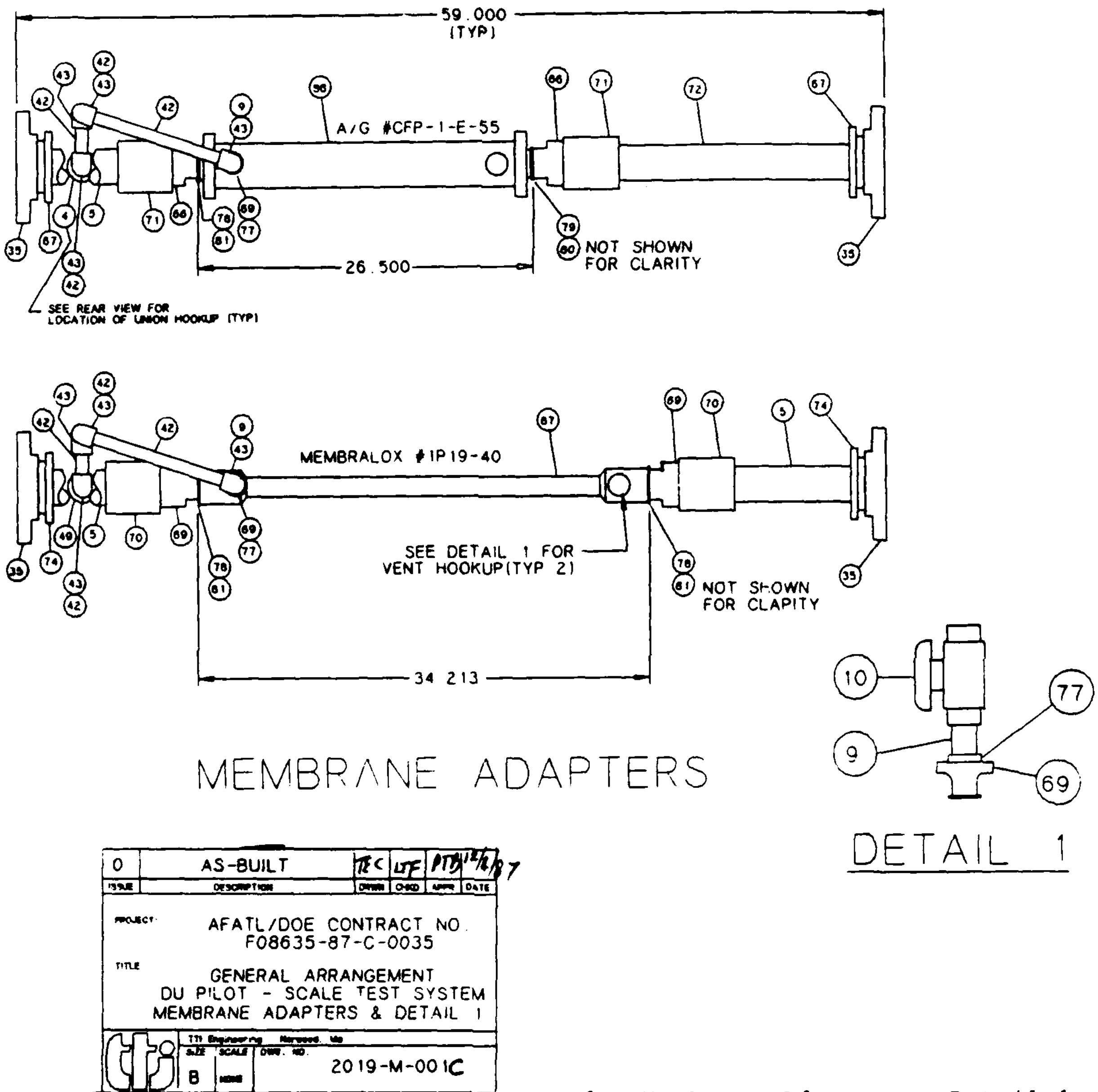
SIZE	SCALE	DWG NO
B	NONE	2019-M-001B





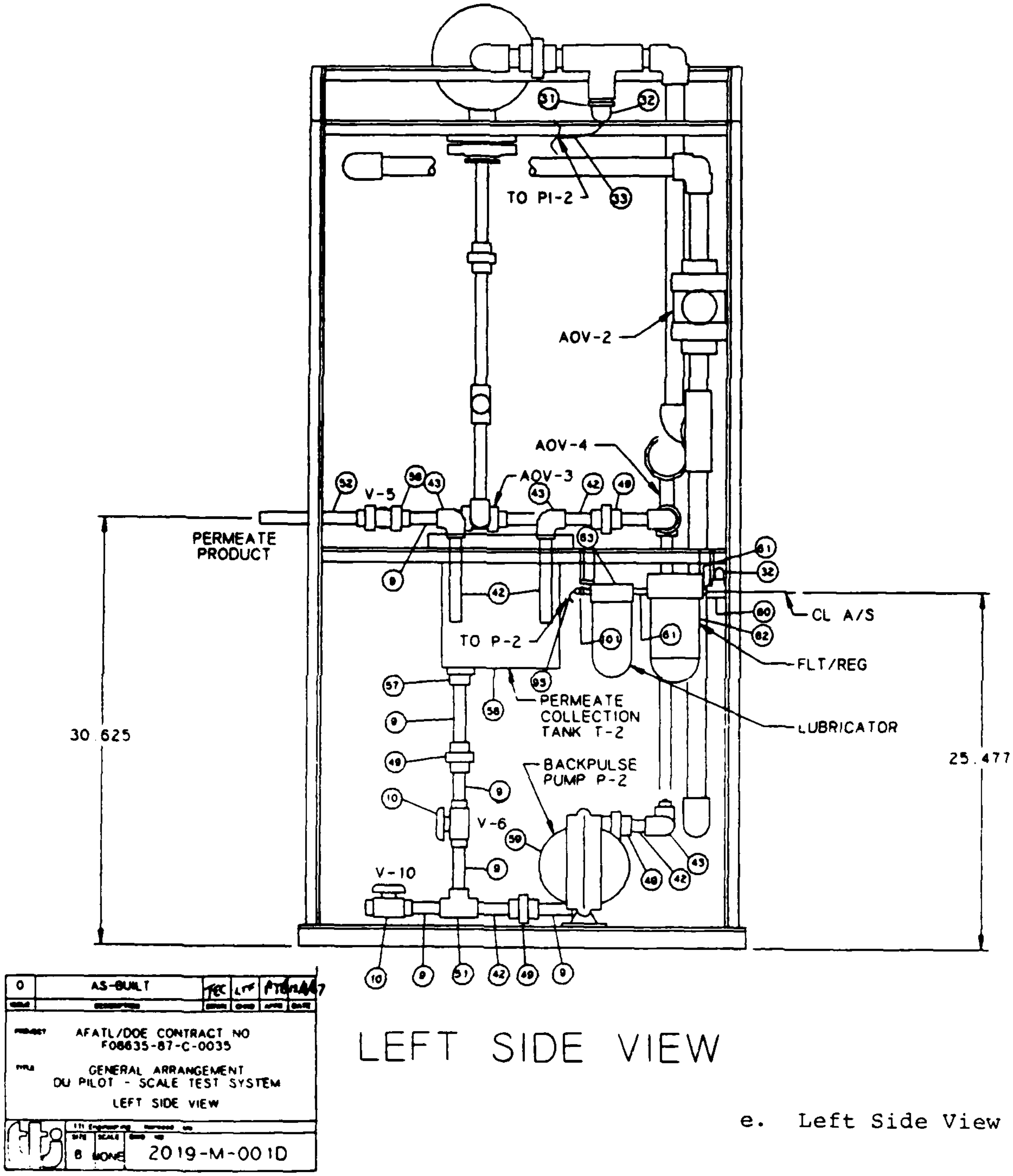
c. Rear View

Figure A-1. General Arrangement (Continued)



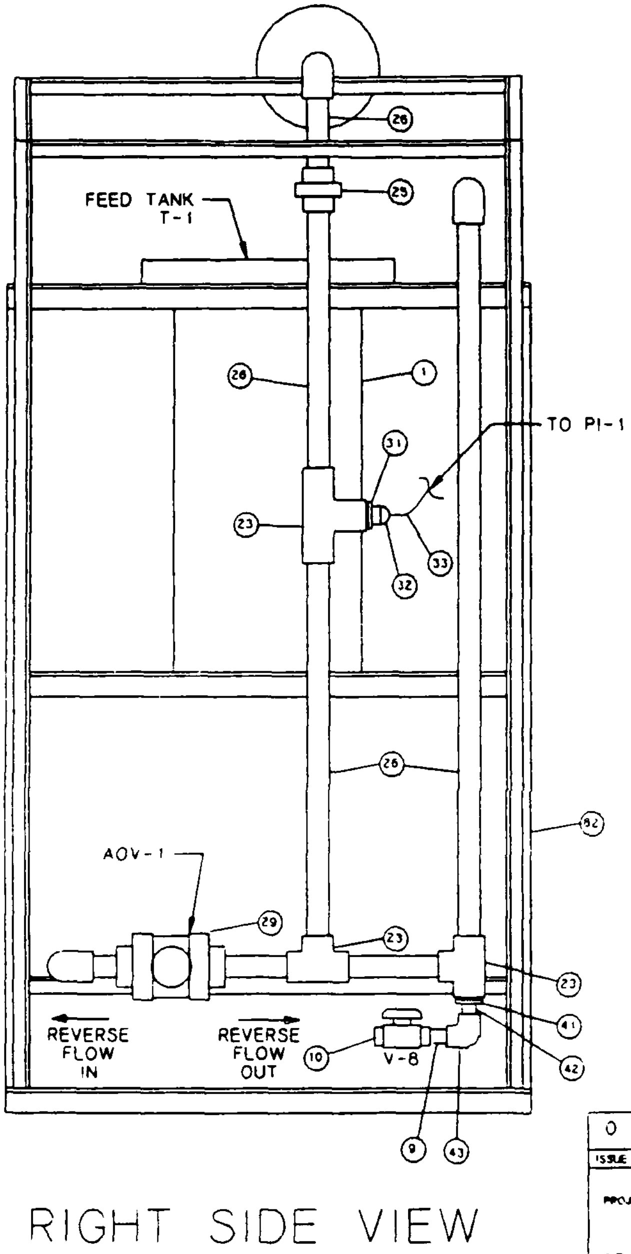
d. Membrane Adapters & Detail 1

Figure A-1. General Arrangement (Continued)



e. Left Side View

Figure A-1. General Arrangement (Continued)

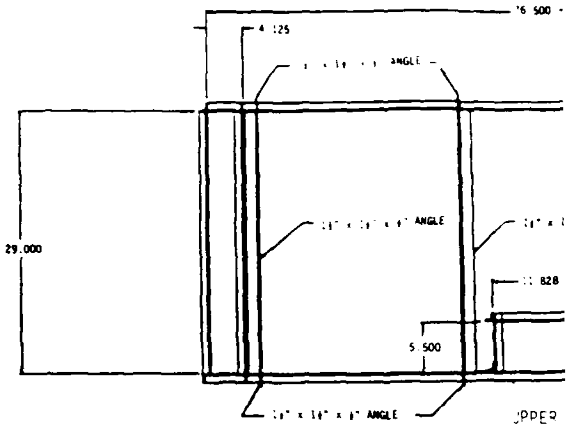


f. Right Side View

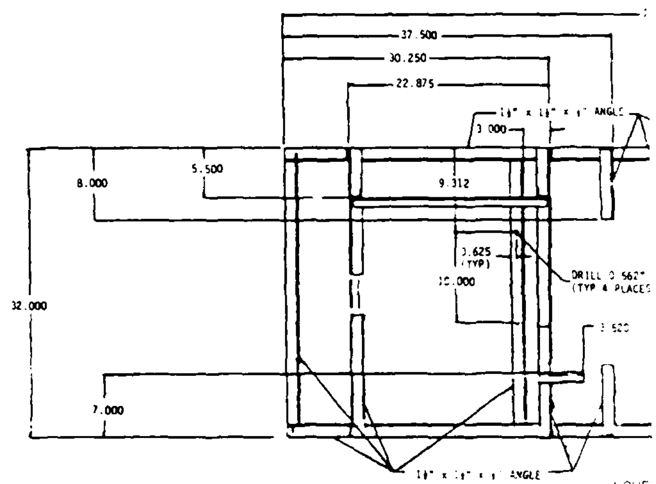
ISSUE	DESCRIPTION	DRWN	CHKD	APPR	DATE
0	AS-BUILT	TEC	JF	PTB	12/4/87

PROJECT	AFATL/DOE CONTRACT NO F08635-87-C-0035
TITLE	GENERAL ARRANGEMENT DU PILOT - SCALE TEST SYSTEM RIGHT SIDE VIEW
	TTI Engineering Norwood Ma
SIZE: B	SCALE: NONE	DWG NO: 2019-M-001E

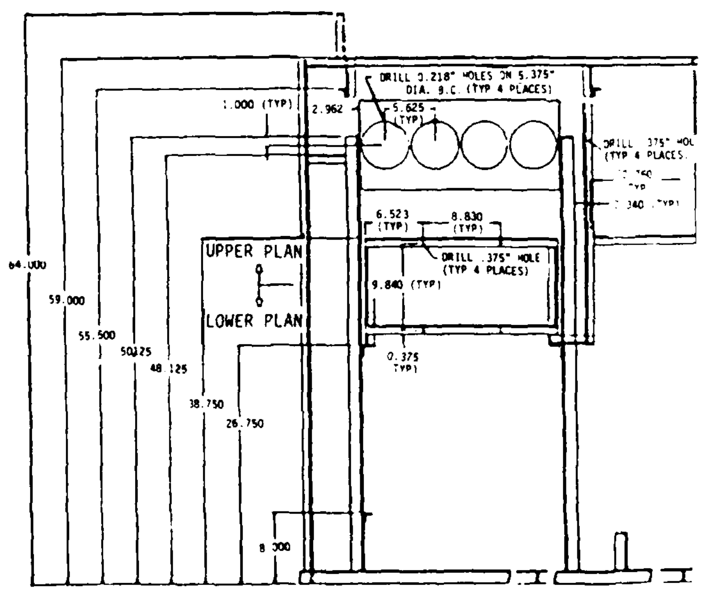
Figure A-1. General Arrangement (Concluded)



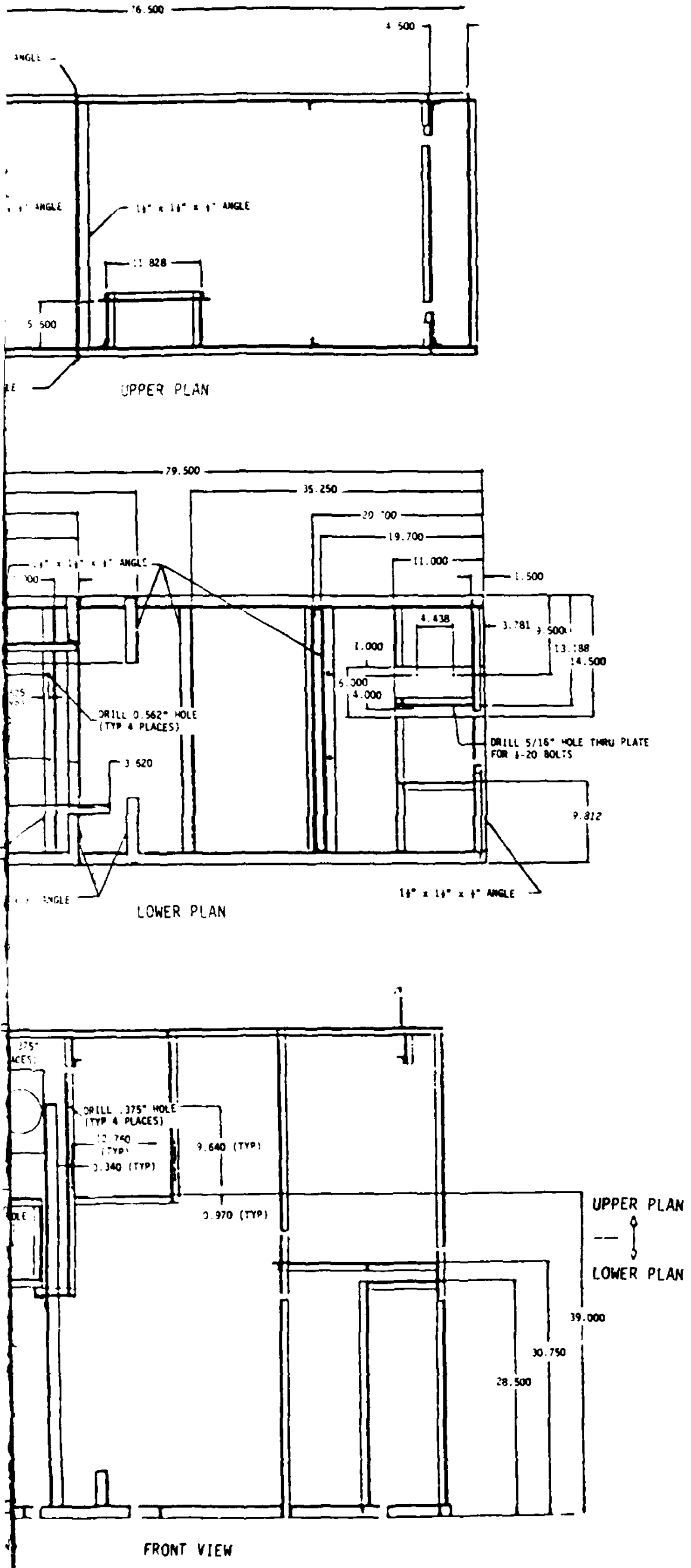
UPPER

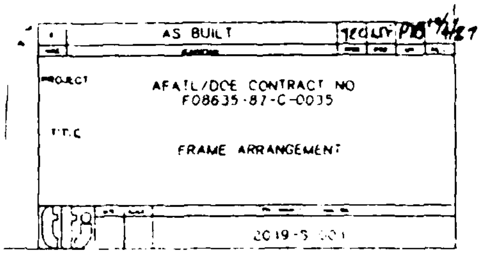


LOWE



FRO

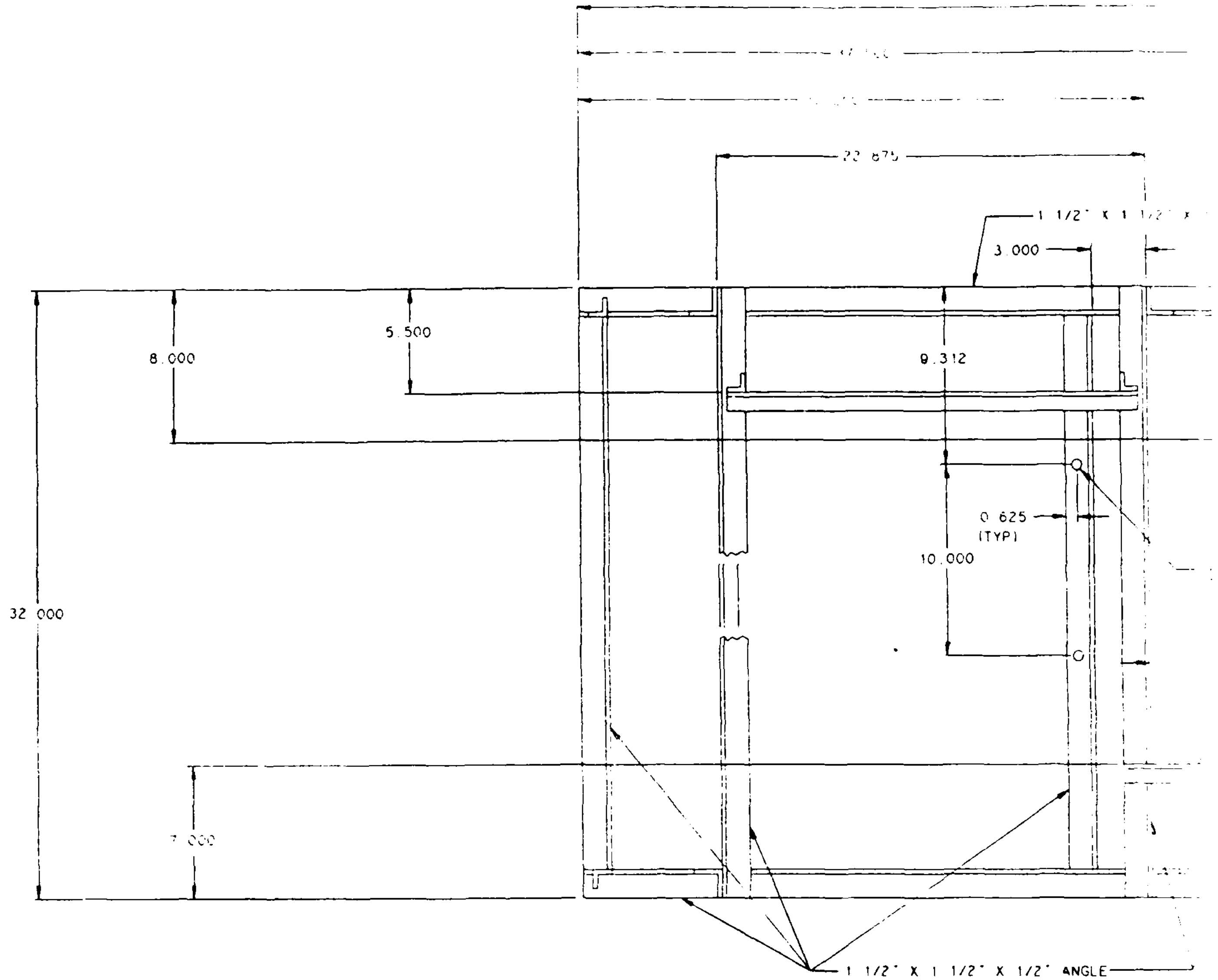




NOTES:
1. ALL STEEL IS 1" x 1" x ⅛" THK ANGLE UNLESS NOTED OTHERWISE

a. Overall Layout

Figure A-2. Frame Arrangement

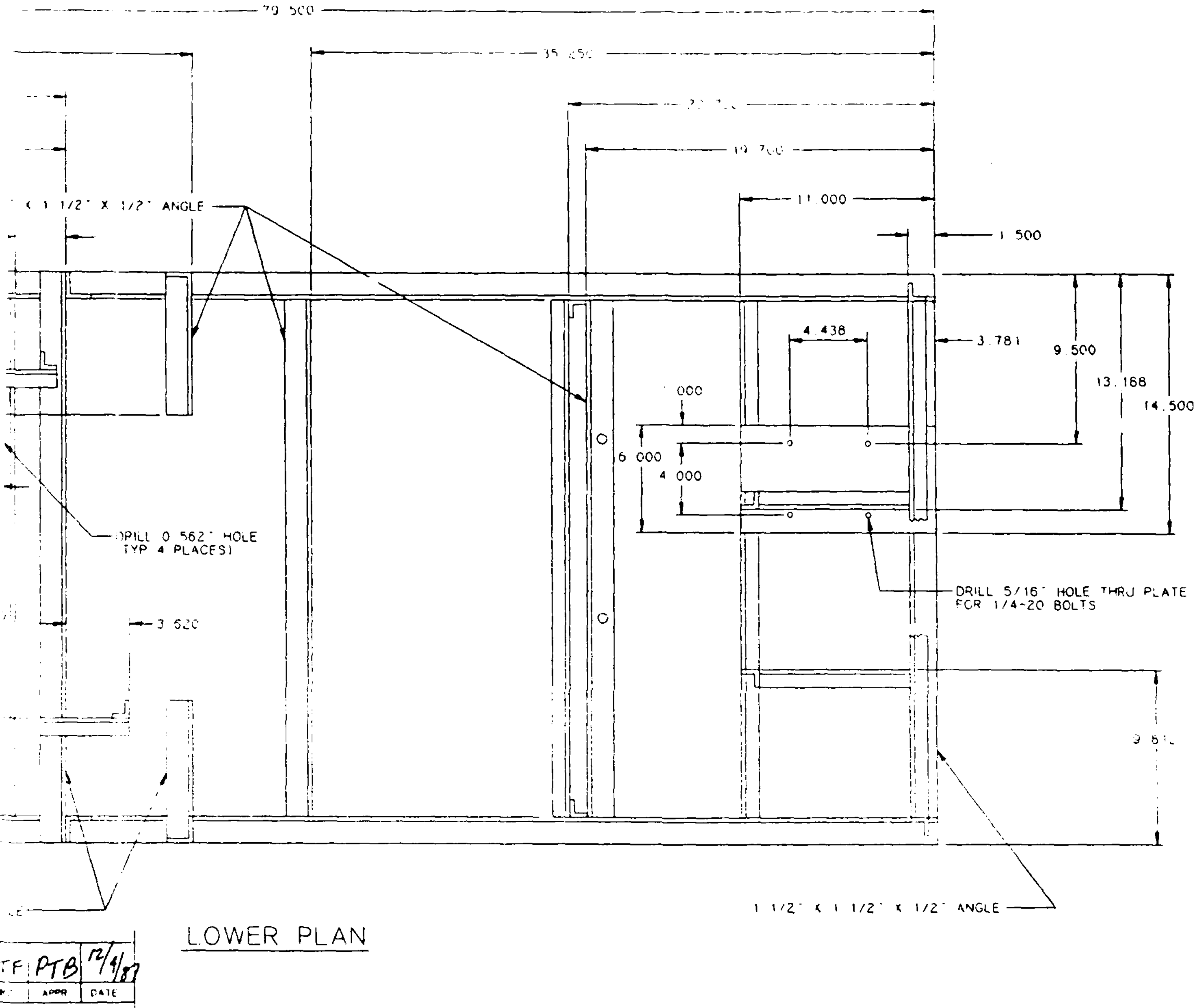


ISSUE	DESCRIPTION	DRWN	CHKD	APPR	DATE
0	AS BUILT	TEC	LTF	PTB	12/4/

PROJECT: AFATL/DOE CONTRACT NO. F08635-87-C-0035

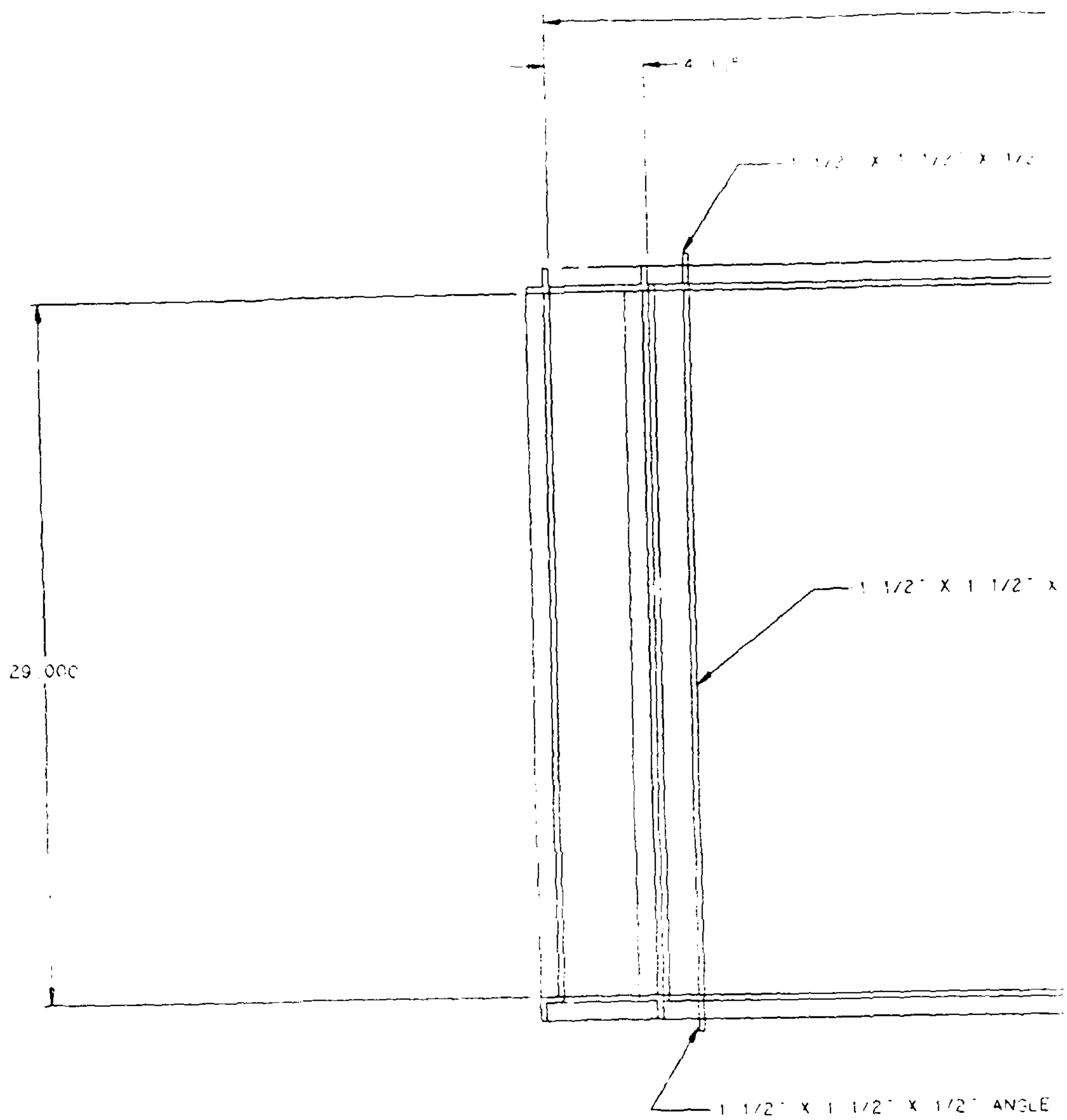
TITLE: FRAME ARRANGEMENT

	SIZE	SCALE	TTI Engineering Norwood Ma
tti			2019-S-001A



b. Lower Plan View

Figure A-2. Frame Arrangement (Continued)

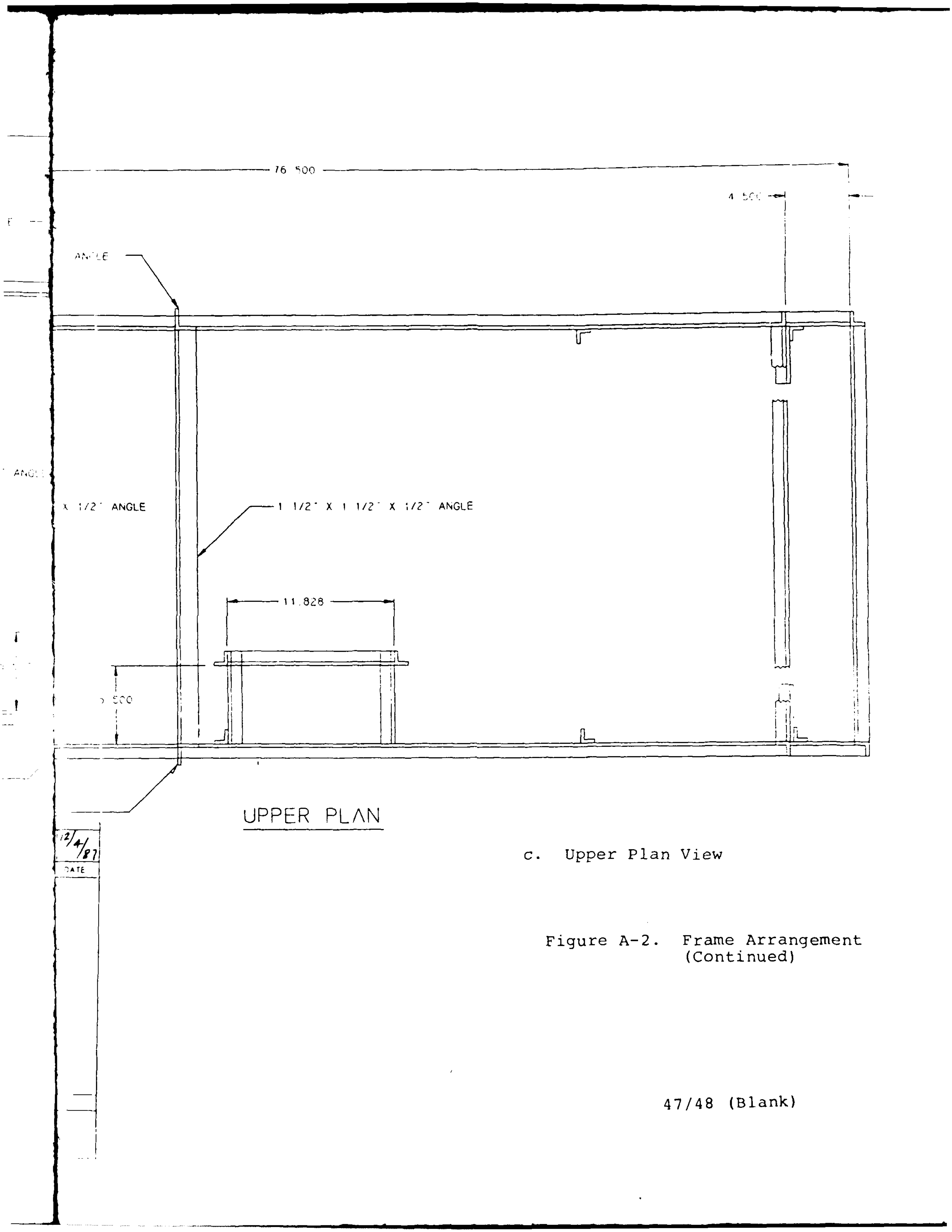


0	AS BUILT	TEC	LTF	PTB
ISSUE	DESCRIPTION	DRWN	CHKD	APPR

PROJECT: AFATL/DOE CONTRACT NO F08635-87-C-0035

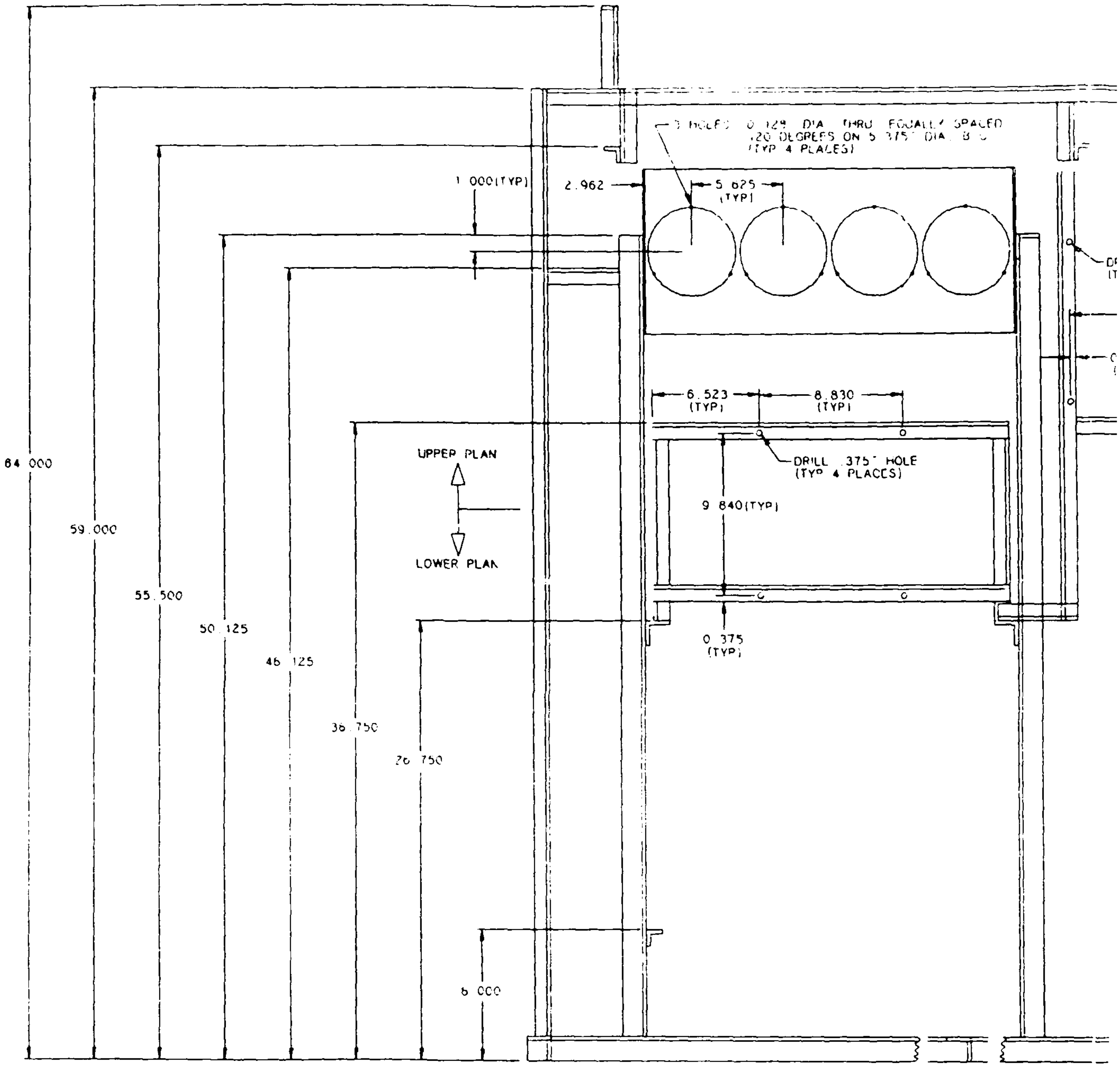
TITLE: FRAME ARRANGEMENT

SIZE	SCALE	TTI Engineering Norwood, Ma
		2019-S-001B



c. Upper Plan View

Figure A-2. Frame Arrangement (Continued)



0	AS BUILT	TEC	LTP	DTB

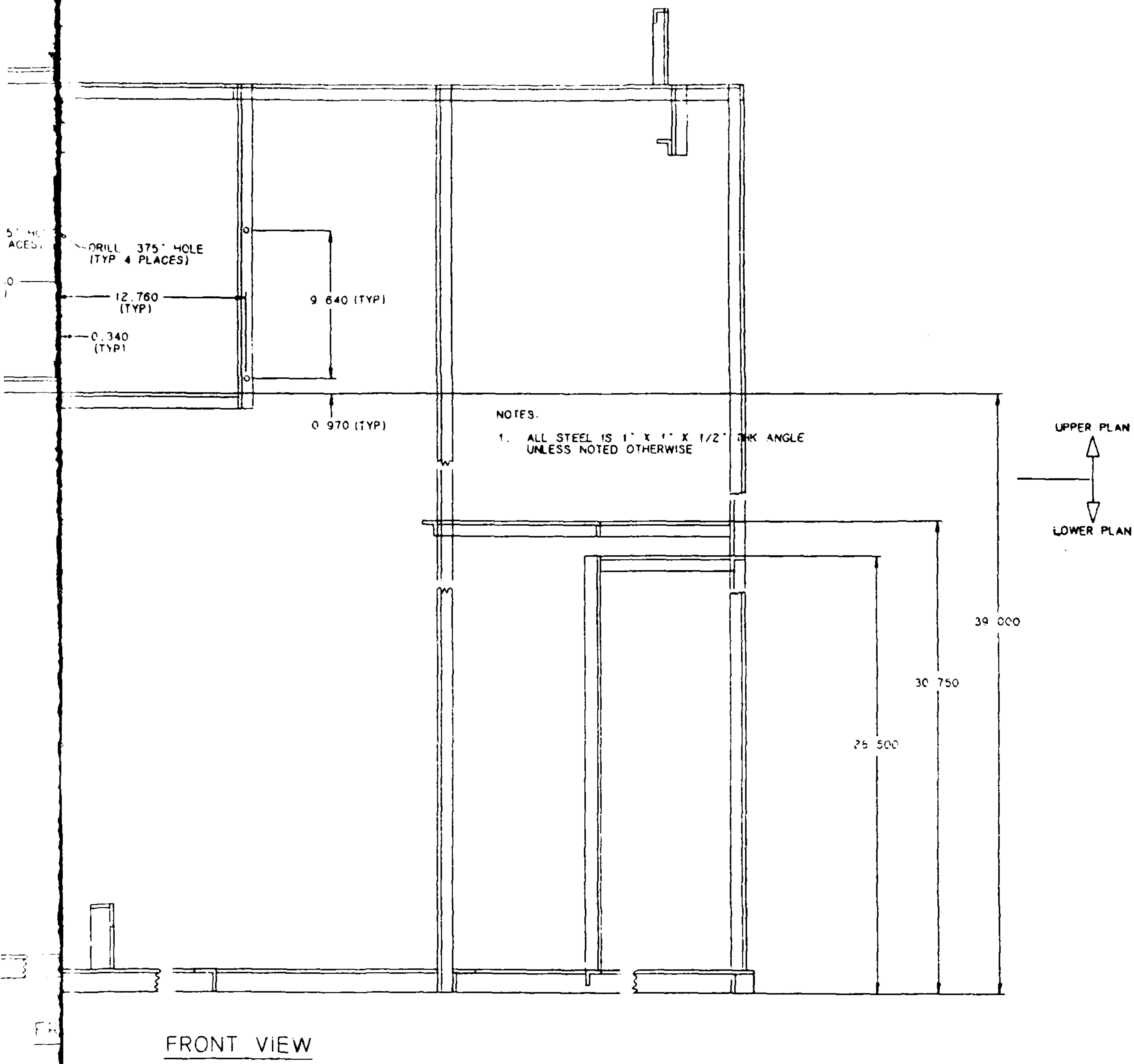
PROJECT

AFATL/DCE CONTRACT NO
F08635-87-C-0035

TITLE

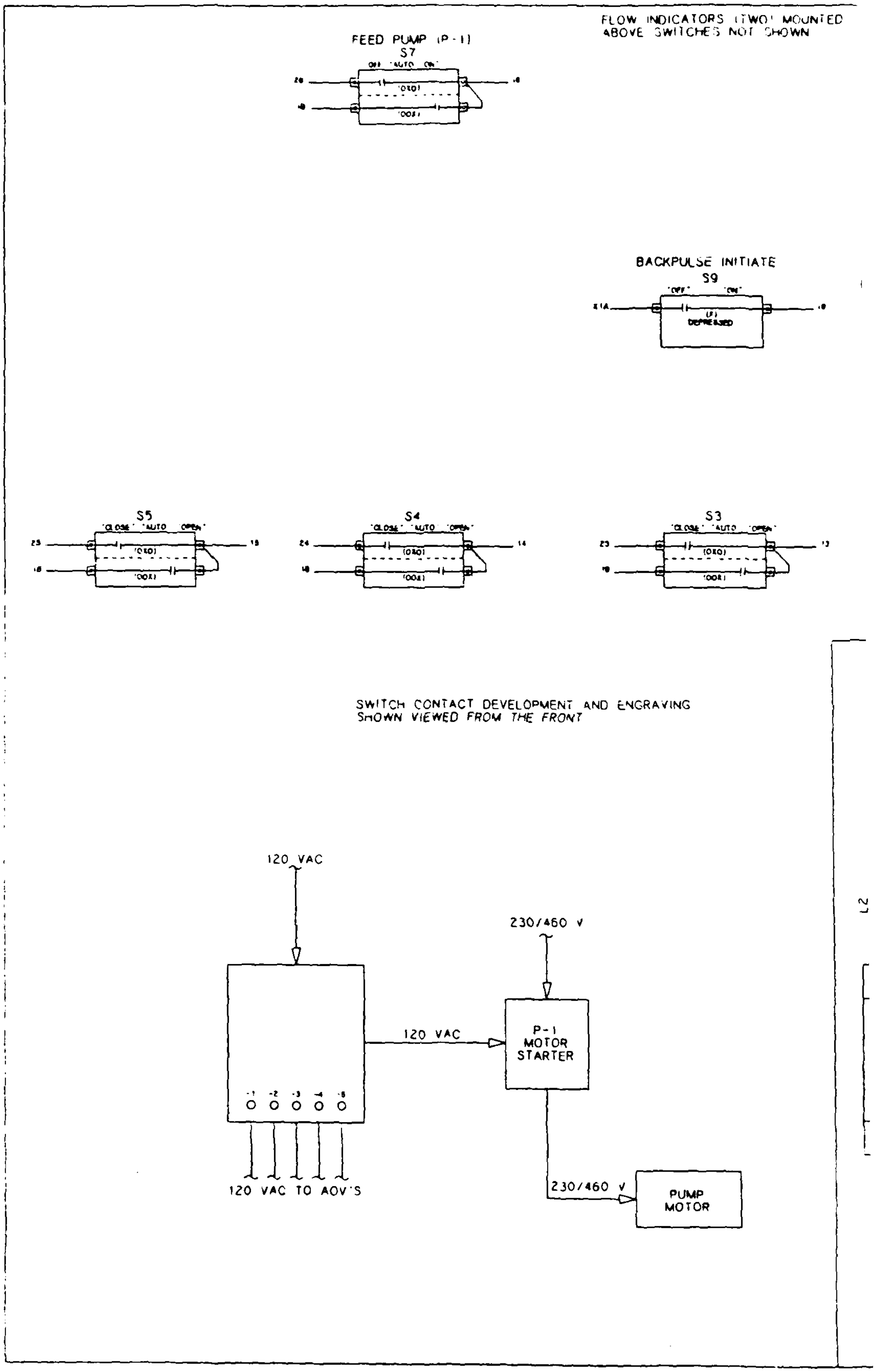
FRAME ARRANGEMENT

20 [illegible] 0010



d. Front View

Figure A-2. Frame Arrangement (Concluded)


FLOW INDICATORS (TWO) MOUNTED ABOVE SWITCHES NOT SHOWN
FEED PUMP (P-1)
S7
BACKPULSE INITIATE
S9
S5
S4
S3
SWITCH CONTACT DEVELOPMENT AND ENGRAVING SHOWN VIEWED FROM THE FRONT
120 VAC
230/460 V
120 VAC
P-1 MOTOR STARTER
120 VAC TO AOV'S
230/460 V
PUMP MOTOR

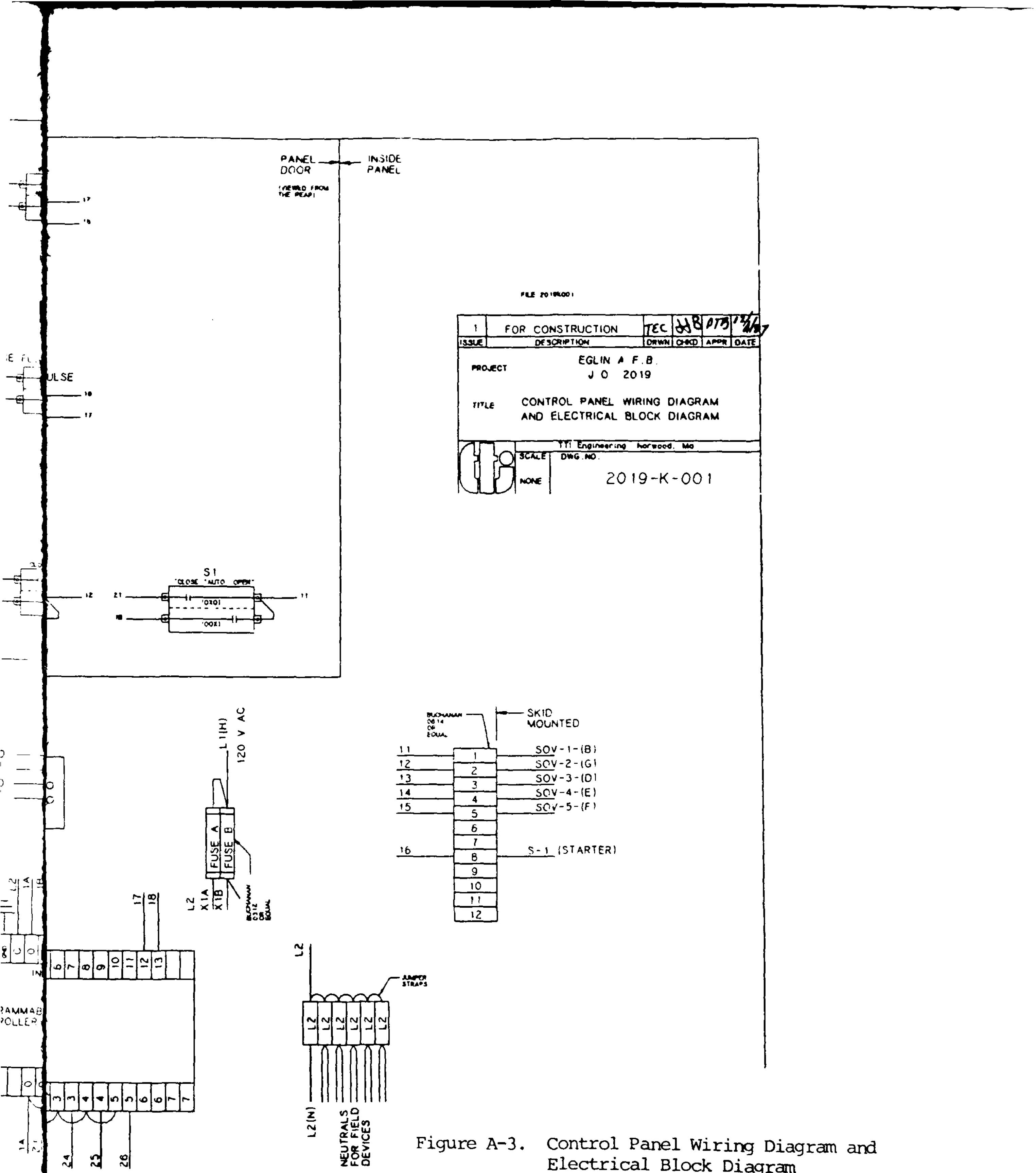


Figure A-3. Control Panel Wiring Diagram and Electrical Block Diagram

Bill of Materials

Item No.	Quantity	Description
Pumps		
30	1	Feed Pump (Tuthill Model #16, with 1 1/2" MNPT Ends)
59	1	Backpulse Pump, Wilden - MI Champ, PPL Const.
Tanks		
1	1	Feed Tank (12 x 12 x 24 - 30 gallons), HDPE, Terracon Stock #103-02, or equivalent
58	1	Permeate Tank (8 x 8 x 8 - 2 gallons), HDPE, Terracon Stock #100-20, or equivalent
Membranes		
40	1	Membrane Module Enka #MD080TP2N
86	1	Membrane Module, A/G #CFP-1-E-55
87	1	Membralox #IP19-40, 0.1 micron
Valves, Manual		
10	7	1/2" Ball Valve (Threaded Ends), PVC, 2-Way
11	1	1 1/2" Ball Valve (Threaded Ends), PVC, 2-Way
24	4	1" Ball Valve (Threaded Ends), PVC, 2-Way
56	1	1/2" Ball Valve, PVC, 3-Way
65	1	1" Pressure Control Valve, Posacon #677, PVC Body, EPDM Diaphragm, Threaded Union Ends
Valves with Actuators		
29	2	1" PVC 3-Way Multi-Port Ball Valve with Air to Spring Actuator
53	2	1/2" PVC Multi-Port 3-Way Ball Valve with Air to Spring Actuator
88	1	1" PVC Air Operated Ball Valve with Spring Return Actuator

Figure A-4 Bill of Materials

Bill of Materials

Item No.	Quantity	Description
I&C		
28	1	Flow Element (Signet #MK508-4 with Installation Fitting #PV8T010, with 1" PVC Pipe Ends)
55	1	Flow Element (Signet #MK-515-P, with 3/8" FNPT Ends)
89	2	Pressure Gauge with Diaphragm Seal, 4 1/2" Face, 0-100 psi, Ashcroft #1279 or equivalent
90	2	Pressure Gauge, 4 1/2" Face, 0-60 psi, Ashcroft #1279 or equivalent
91	5	3-Way Solenoid Valve, ASCO #8320A186 or equivalent
Piping and Fittings		
2	1	1 1/2" PVC Tank Adapter
3	6	1 1/2" PVC Pipe Nipple T.O.E.
4	2	1 1/2" PVC Union (Socket Ends)
5	10 L.F.	1 1/2" PVC Sch. 80 Pipe
6	5	1 1/2" PVC 90° Elbow (Socket Ends)
7	1	1 1/2" x 1 1/2" x 1 1/2" PVC Tee (Socket Ends)
8	3	1 1/2" x 1/2" Reducing Bushing (Male Slip x Socket), PVC
9	12	1/2" Pipe Nipple T.O.E., PVC (lengths vary)
12	1	1 1/2" x 3 LG. PVC Pipe Nipple
13	2	1 1/2" PVC Flange (Threaded)
18	2	Pump Connector 1 1/2" x 9" LG., 304 S.S., Braided Hose, 150 lb. Flanged Ends
19	4	1/2" PVC Threaded Coupling
21	1	1 1/2" x 1" PVC Reducing Bushing, Male Slip x Socket
22	10	1" PVC Pipe Nipple T.O.E. (lengths vary)
23	7	1" x 1" x 1" PVC Tee (Socket Ends)

Figure A-4 Bill of Materials (Continued)

Bill of Materials

Item No.	Quantity	Description
Piping and Fittings (continued)		
25	8	1" PVC Union (Socket Ends)
26	60 L.F.	1" Sch. 80 PVC Pipe
27	15	1" PVC 90° Ell (Socket Ends)
31	2	1" x 1/2" PVC Reducing Bushing (Male Slip x FPT)
34	2	3" x 1" PVC Reducing Bushing (Male Slip x Socket)
35	6	3" PVC Flange (Socket Type)
41	1	1" x 1/2" PVC Reducing Bushing (Male Slip x Socket)
42	40 L.F.	1/2" Sch. 80 PVC Pipe
43	10	1/2" PVC 90° Ell (Socket Ends)
44	8	1 1/2" PVC Flange (Socket Ends)
49	8	1/2" PVC Union (Socket Ends)
51	3	1/2" x 1/2" x 1/2" PVC Tee (Socket Ends)
52	3	1/2" x 6" LG. PVC Pipe Nipple
54	2	1/2" x 3/8" PVC Reducing Bushing (Male Slip x FPT)
57	1	1/2" PVC Tank Adapter
60	1	1/2" x 1/2" x 1/2" Threaded Tee, Brass
61	3	1/2" Pipe Nipple x 2" LG. Brass
62	2	Air Filter/Regulator with Mounting Bracket, Speedaire #7Z553 or equivalent
63	1	Air Lubricator, Speedaire #2Z458 or equivalent
66	2	2 1/2" K22 Adapter (TCI Superior), 316 S.S. const.
67	2	3" x 2 1/2" PVC Reducing Busing (Male Slip x Socket)
69	6	1 1/2" K22 Adapter (TCI Superior), 316 S.S. const.

Figure A-4 Bill of Materials (Continued)

Bill of Materials

Item No.	Quantity	Description
Piping and Fittings (continued)		
70	4	1 1/2" PVC Male Adapter
71	2	2 1/2" PVC Male Adapter
72	4 L.F.	2 1/2" Sch. 80 PVC Pipe
74	2	3" x 1 1/2" Reducing Bushing (Male Slip x Socket)
75	1	1/2" PVC Union, Threaded Ends
76	2	3/8" PVC Pipe Nipple x 3" LG.
77	4	1 1/2" x 1/2" PVC Pipe Nipple x 3" LG.
Bolts/Nuts/Washers/Gaskets/Clamps		
14	24	1/2" x 2 1/4" LG. Machine Bolts
15	32	1/2" Hex Nuts
16	64	1/2" Washer
17	8	1 1/2" Full Face Black Rubber Gasket
36	8	5/8" x 3" LG. Machine Bolts
37	8	5/8" Hex Nuts
38	16	5/8" Washers
39	6	3" Full Face Black Rubber Gasket
45	8	1/2" x 2 1/4" Machine Bolts
78	6	1 1/2" K40 Gasket
79	2	2 1/2" K40 Gasket
80	2	2 1/2" K13HH Klamp (TCI Superior), 316 S.S. const.
81	6	1 1/2" K13HH Klamp (TCI Superior), 316 S.S. const.

Figure A-4 Bill of Materials (Continued)

Bill of Materials

Item No.	Quantity	Description
Electrical Supplies		
84	1	Control Panel, Rittal #KS 1444, FRP or equivalent
85	1	Motor Starter Panel, Rittal #KS 1434, FRP or equivalent
96	10	3-Position Selector Switch with Cont. Block
97	1	Push Button with Block
98	3	2-Position Selector Switch
99	1	Contactor Breaker, Telemecanique Integral 32 Contactor Breaker or equivalent
100		Miscellaneous Electric Flexible Conduit and Fittings
Structural Steel		
82	40 L.F.	1 1/2" x 1/4" Tk. Angle, C.S.
83	80 L.F.	1" x 1/4" Tk. Angle, C.S.
Tubing and Tube Fittings		
32	8	1/2" MNPT x 3/8" Tube Legris Fitting
33	30 L.F.	3/8" O.D. Tubing
92	5	1/4" x 1/8" Hex Reducing Nipple, Cajon
93	5	1/4" Tube x 1/8" MNPT, Legris
94	5	1/4" x 1/4" x 1/4" Tube Tee, Legris
95	25 L.F.	1/4" Legris Tubing
101	6	1/4" MNPT x 1/4" Tube, Legris

Figure A-4 Bill of Materials (Concluded)

APPENDIX B

FILTRATION SYSTEM FOR REMOVAL OF DEPLETED
URANIUM FROM WATER: TASK 1 TEST PLAN (CDRL ITEM NO. A005),
JUNE 26, 1987

FILTRATION SYSTEM FOR REMOVAL OF

DEPLETED URANIUM FROM WATER:

TASK 1 TEST PLAN
(CDRL Item No. A005)

Prepared Under Contract No. F08635-87-C-0035

TTI J.O. No. 2019
for
Department of the Air Force
Armament Division
Eglin AFB, FL 32542-5320

by

TTI Engineering
333 Providence Highway
Norwood, MA 02062

June 26, 1987

1.0 INTRODUCTION

TTI Engineering has been awarded Contract No. F08635-87-C-0035 to remove depleted uranium (DU) and DU compounds from water using a pilot-scale, crossflow microfiltration (MF) system. The pilot MF system has been designed and sized by TTI to allow direct scale-up to a production system that will be capable of treating 500 to 35,000 gallons of water containing:

1. DU concentrations from 2.5×10^{-5} to 9×10^{-8} microcuries/mL

2. DU particles in the 0.1 to 10 micron size range.

All particles in the 0.1 to 10 micron size range will be filtered by the pilot system. As discussed in our Proposal No. 87034-1, we assume that this amount of filtration will produce water that is low enough in activity for onsite disposal in accordance with the NRC standard of 35 pCi/g of soil.

TTI will test the pilot system at Nuclear Metals, Inc., in Concord, Massachusetts, where the DU waste water experienced at Eglin AFB will be duplicated and batch-fed to the test system.

The production system design for an apparatus containing MF modules is dependent upon the accuracy of the selected module's performance data. Membrane manufacturers typically do not have performance data for the myriad of processes that are encountered. A pilot-test program is essential to fill data gaps before a cost-effective production system can be designed.

2.0 TEST OBJECTIVES

The objectives of the test program are:

1. Remove up to 1% (wt.) concentration of DU and DU compounds from water so that:

    a. Filtered water (permeate) can be disposed of onsite without exceeding 35pCi/g of soil (NRC standard) or any other applicable standard.

    b. Particles in the 0.1 to 10 micron range are not present in the filtered water.

2. Compare the performance of three membrane modules for achieving #1 above:

    a. Membralox #1P19-40, 0.1 micron pore size
    b. A/G Technology #CFP-1-E-55, 0.1 micron pore size
    c. ENKA #MD080TP2N, 0.2 micron pore size

3. Establish optimum operating parameters for scale-up to a production system:

    a. Transmembrane dP
    b. Mechanical cleaning, i.e., backpulse frequency, duration and pressure
    c. Permeate flux rate (filtered water flow rate).

3.0 TEST APPARATUS

Figure 1 presents a schematic of the Pilot-Scale Test System. The system is constructed with PVC and allows direct scale-up to a production-sized system.

The system will allow a nominal feed rate of 10 gpm which can be either recirculated to the Feed Tank or pumped to a separate concentrate product tank after the feed flows through the test module. Permeate product (filtered water) can be collected separately, in a Permeate Collection Tank (reservoir for backpulsing), or returned to the Feed Tank to maintain a constant solids content in the feed.

Automatic cleaning can be accomplished using a:

1. Backpulse
2. Fast Flush
3. Coincident backpulse and fast flush, or
4. Reverse flow configuration.

Manual, chemical cleaning is possible by batch-loading the recommended cleaning solution into the Feed Tank.

A thirty gallon sample will be batch-loaded into the Feed Tank and agitated. Membrane modules several inches in diameter by three feet in length can be tested on the test apparatus.

To begin operation of the system, Valve #V-2 is opened and Valve #V-3 is closed. Flow is established through the recirculation loop. Valve #V-2 is slowly closed while Valve #V-3 is slowly opened to pump feed to the test module. Permeate flows through Valve #V-4, Air-Operated Valve #AOV-3, and Valve #V-5 to a receiver. Concentrate product from the test module is returned to the Feed Tank via Air-Operated Valve #AOV-2 and the manual Pressure Control Valve (PCV). The PCV is used to establish the optimum pressure drop across the test module.

Periodic cleaning is performed on a timed cycle that is logic controlled. A backpulse, fast flush, or reverse flow mode is activated, typically one to two seconds every two to four minutes, to remove solids within the channels (tubes) of the test module.

Both the Feed Pump #P-1 and Backpulse Pump #P-2 continually operate for modules that require backpulsing. During a backpulse, #AOV-3 and #AOV-4 are energized reversing permeate flow from the Permeate Collection Tank #T-2 to the shell side of the module. By timing the backpulse, a pre-determined permeate volume at a specific pressure "backpulses"

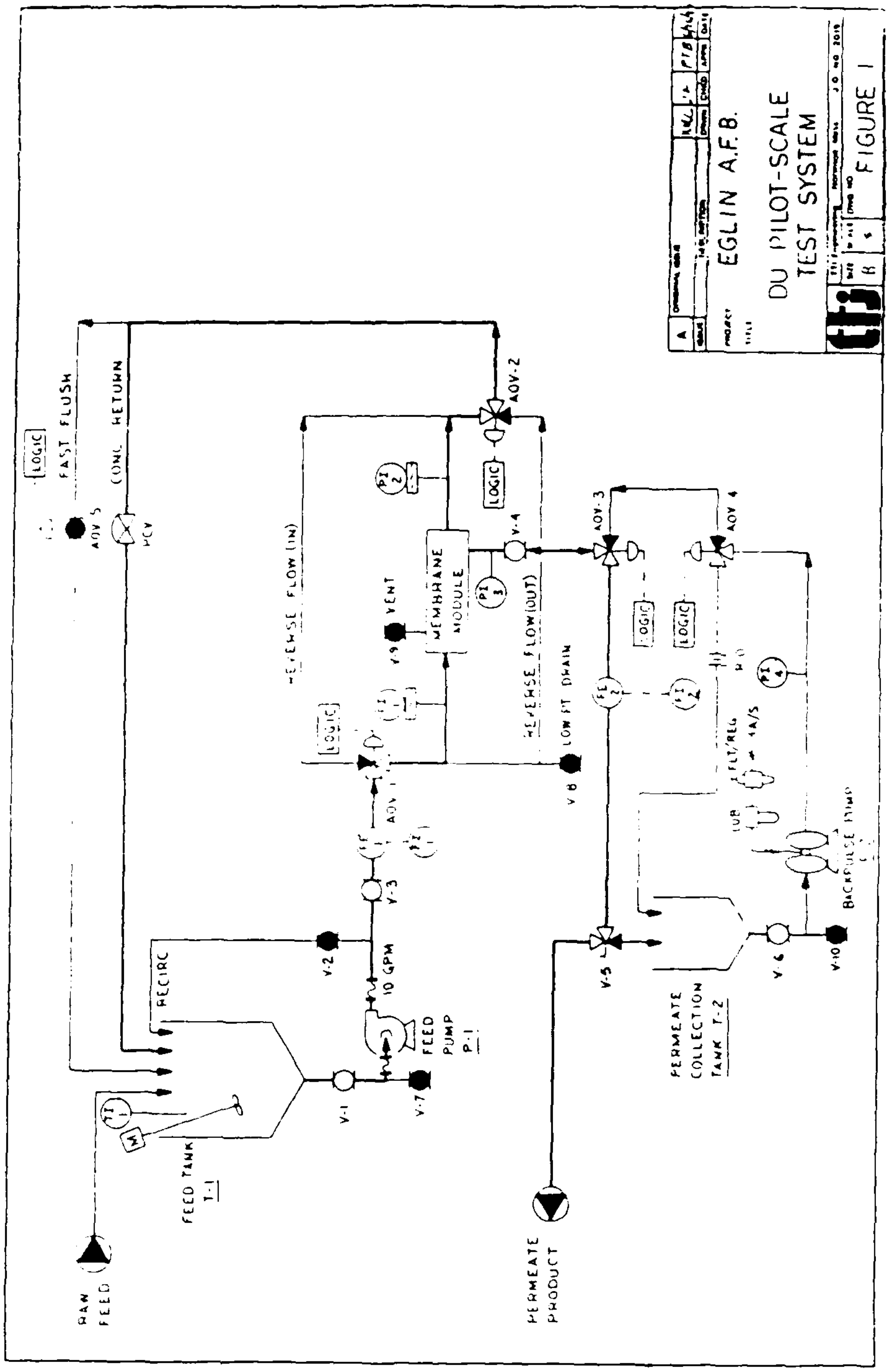


Figure B-1. DU Pilot-Scale Test System

through the membrane dislodging solids from the dynamic layer on the concentrate (tube) side of the membrane. The uninterrupted feed flow flushes the dislodged solids from the module and returns them to the Feed Tank.

If a fast flush is used during a backpulse, #AOV-5 is energized at the same time as #AOV-3 and #AOV-4. Line pressure is reduced for the concentrate return, thereby increasing the concentrate return flow rate. The increased flow velocity enhances flushing of solids from the test module. Fast flushing can be independent from or coincident with backpulsing.

Reverse flow through the test module is accomplished by energizing #AOV-1 and #AOV-2. Feed flow then enters the test module at the concentrate product connection and exits at the feed connection. Backpulsing is normally not done on modules requiring reverse flow for cleaning, although both backpulsing and fast flushing can be done on the test system during a reverse flow cycle.

4.0 TEST PROCEDURE

1. Establish the following initial valve alignment:

V-1	Open
V-2	Closed
V-3	Closed
V-4	Open
V-5	Aligned for Permeate Product
V-6	Open
V-7	Through V-10 Closed
AOV-1	Through AOV-5 Deactivated

2. Activate the membranes as recommended by the manufacturer (see Appendix A).

3. Fill the module (see Appendix B-1) and vent any trapped air using Valve V-9.

4. Fill a one-liter, glass sample jar with a well-mixed feed sample.

5. Record initial volume in feed tank on data sheet (see Appendix B-2).

6. Set logic for recommended cleaning cycle for membrane module.

7. Open Valve #V-2

8. Fill Tank #T-2 with one gallon of D.I. water.

9. Establish recommended backpulse flow rate

   a. Open Valve #V-6 and air supply valve to Pump #P-2.

   b. Regulate the air supply to #P-2 and establish the required pressure PI-4. (PI-4 and the regulated air supply pressure must be selected from the P-2 performance curve to correspond with the recommended backpulse flow rate for a given module).

10. Turn on Pump #P-1.

11. Partially close #V-2 and partially open #V-3 to establish a dynamic layer on the membrane (approximately 10 minutes) at a low flow velocity. Valve #V-4 may be closed or open for this step. Refer to Appendix B-1 for the given module and properly align #V-4.

12. Fully close #V-2 and fully open #V-3; Open #V-4.

13. Adjust Pressure Control Valve (PCV) to obtain desired transmembrane dP.

14. Record initial data on data sheet.

    a. Time of day
    b. Flow rates FE-1 and FE-2
    c. Pressures PI-1 through PI-4
    d. Feed Tank temperature TI-1.

15. Energize logic.

16. Observe mechanical cleaning cycle to confirm frequency and duration of pulse. Enter cycle information on data sheet.

17. Record entries on data sheet at 15-minute intervals:

    a. Repeat 14 a. through 14 d. above
    b. Record cleaning cycle information.

18. Align #V-5 to refill Tank #T-2 as required.

19. Fill one-liter glass sample jars with Concentrate Return and Permeate Product samples at one-hour intervals.

20. Open #V-2; Close #V-3; and de-energize logic when approximately 80% of initial feed volume has been recovered.

21. Turn off #P-1 and air supply to #P-2.

22. Close #V-2 and #V-4.

23. Open #V-8 and drain module.

24. Replace module with next unit to be tested.

25. Return to Step #1.

26. Clean modules as recommended (Appendix B-1) after tests completed.

The test procedures will be followed for two test series. The first test series will be followed by a Program Review meeting (PR-2) at TTI. Documented levels of radioactivity and characterization of residual DU for collected feed and permeate samples will be discussed; and recommendations for additional tests, if required to maximize removal of DU, will be presented by TTI. The second test series will be conducted based on the results of PR-2, and after approval has been obtained to proceed.

5.0 SAMPLE AND DATA ANALYSIS

1. Analyze collected feed and permeate samples:

   a. DU and DU compounds, pCi/g

      1. gamma radiation by Nuclear Data #ND6 Analyzer
      2. alpha radiation by proportional counter-aliquot of sample onto Millipore filter, dry, and count

   b. Residual DU, mg/L

      1. Fluorometric analysis for concentrations less than 100 ppb

      2. Colorimetric or Atomic Absorption analysis for concentrations greater than 100 ppb

   Note: The above procedures are standard for NMI.

2. Calculate permeate flux rate, f, gal/ft.^{2}/hr/bar

   f = (FE2 * 60)/((Eff. Membrane Area of Module, ft^2) * (Transmembrane dP/14.5))

3. Compare modules for:

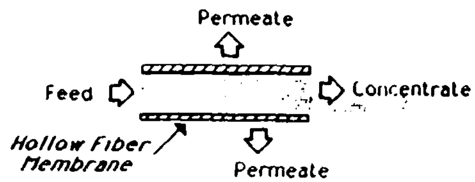
   a. f versus % solids
   b. DU and DU compounds removal efficiency
   c. pCi/g of DU and DU compounds in permeate.

APPENDIX B-1

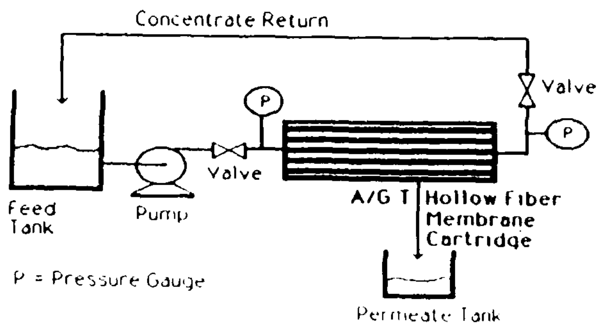
Membrane Modules' Operating Instructions

INTRODUCTION

A/G Technology Corporation hollow fiber membrane cartridges are available in a wide range of membrane pore sizes, fiber diameters, and cartridge dimensions. Each cartridge contains a multitude of polysulfone hollow fibers potted in parallel within a plastic housing. The ***feed*** stream flows through the inside of the fibers and is typically recirculated as the ***concentrate*** stream. ***Permeate*** passes through the membrane walls and is collected on the shell-side of the cartridge.



For laboratory or pilot applications, a basic manual control system consists of a pump, feed reservoir, permeate collection reservoir, pressure gauges, and valving. Permeate connections should be of flexible tubing.



A/G Technology Corporation offers the broadest range of ultrafiltration and microfiltration hollow fiber membrane pore sizes, internal diameters and cartridge sizes in the industry. This diverse product line provides the research scientist with complete scale-up capability. Furthermore, the unique membrane morphology provides unsurpassed membrane integrity.

ULTRAFILTRATION

5,000 NMWC
10,000 NMWC
30,000 NMWC
100,000 NMWC
500,000 NMWC

MICROFILTRATION

0.1 Micron
0.2 Micron
0.45 Micron

A/G TECHNOLOGY HOLLOW FIBER CARTRIDGES

HOUSING IDENTIFIER	HOUSING DIAMETER (in)	FIBER INTERNAL DIAMETER (mm)	NOMINAL MEMBRANE AREA PER CARTRIDGE (ft2)
Laboratory-Scale			
3	3/8	0.5	0.16
		0.75	0.1
		1	0.08
4	3/4	0.5	0.7
		0.75	0.5
		1	0.35
5	1-1/4	0.5	3
		0.75	2
		1	1.5
6	1-1/4	0.5	6
		0.75	4
		1	3
7	1-1/4	1	6
Process-Scale			
35	3	0.5	14
		1	8.5
55 or 55R	3	0.5	36
		1	23
75 or 75R	3	1	40

OPERATING PRECAUTIONS

1. **Flush** ultrafiltration cartridges for one hour prior to use to remove preservative solution
2. Do **NOT** allow ultrafiltration cartridges to dry out
3. Do **NOT** shock membrane cartridges during handling nor expose to pressure surges during operation
4. Do **NOT** clamp cartridges too tightly, housings & endfittings are plastic
5. Do **NOT** autoclave *process-scale microfiltration* cartridges (Housing Sizes 35, 45, 55, 55R, 75, and 75R)
6. A strainer or prefilter with a 200 micron rating may be desirable depending on feed characterics and hollow fiber internal diameter

GENERAL OPERATING CONDITIONS

Membrane life is dependent upon feed pressure, temperature, pH and composition. General guidelines for extending membrane life are

Operating Parameter	Ultrafiltration	Microfiltration
Recommended Operating Pressure (psig)	up to 30	3 to 10*
Maximum Pressure @ 25 C (psig)	35	20
Maximum Temperature @ pH = 7 & 25 psig (C)	80	80
Maximum Continuous Chlorine Exposure (ppm)	200	200
pH Range @ 25 C	2 to 13	2 to 13
Shipping Preservative	Glycerine	None
Autoclavable**	No	Lab-Scale Yes Process-Scale No

* Microfiltration cartridges typically provide more stable flux over time operated at low transmembrane pressure. 0.45 micron cartridges should be operated at 20 psig maximum (preferrably 10 psig, maximum)

** Process scale cartridges are NOT autoclavable

LABORATORY-SCALE CARTRIDGES

1. Operate microfiltration cartridges at minimum pressure initially, typically 3 to 5 psig. Increase pressure gradually, if needed to 10 psig.
2. Provide feed flowrates on polarizing streams of the following magnitude for ultrafiltration cartridges:

Cartridge Housing Identifier	Feed Flowrate (liters/min)	Feed Flowrate (gallons/min)
3	2 to 3	0.5 to 0.8
4	8 to 12	2 to 3
5	15 to 20	4 to 5
6	15 to 20	4 to 5
7	15 to 20	4 to 5

3. For non-polarizing streams, reduce flowrates in above table by a factor of 2 to 3

PROCESS-SCALE CARTRIDGES

1. Operate microfiltration cartridges at minimum pressure initially, typically 3 to 5 psig. Increase pressure gradually, if needed to 10 psig
2. Provide feed flowrates on polarizing streams of the following magnitude for ultrafiltration cartridges

Cartridge Housing Identifier	Hollow Fiber Internal Diameter	Flowrate (gallons/min)
35 or 45	0.5 mm	15 to 20
	1 mm	30 to 38
55 or 55R	0.5 mm	15 to 20
	1 mm	30 to 38
75 or 75R	1 mm	30 to 38

3. For non-polarizing streams, reduce flowrates in above table by a factor of 2 to 3

CLEANING

Cleaning formulations and the frequency and duration of cleaning cycles are highly dependent on the nature of the feed stream and extent of the concentration. In general, cleaning should be performed at low pressure and high velocity, at temperatures of 40 to 50 C. Typical cleaning formulations are

1. Sodium hypochlorite at up a 300 ppm concentration
2. Sodium hydroxide at up to pH 12
3. Detergent cleaners such as Tergezyme® or Micro® at up a 0.5% concentration

Before cleaning flush residual feed from cartridge with clean water. After cleaning flush residual cleaning agent from cartridge.

In processing of protein solutions, flush with buffer solution prior to cleaning.

The fibers may be backflushed with permeate at pressures of 2 to 5 psig provided a low velocity (about 0.5% of feed rates given above) is used. During backflushing, do not shock the membrane with pressure surges.

STERILIZATION

Ultrafiltration and Microfiltration cartridges of all sizes may be sterilized via chemical means. Laboratory-scale microfiltration cartridges may be autoclaved.

Laboratory-scale microfiltration cartridge autoclave conditions are 121 C for 20 minutes. This procedure is acceptable for Cartridge Housing Sizes 3, 4, 5, 6 and 7. The cartridges may be autoclaved multiple times without change in membrane performance, however the exact number of autoclave cycles is site-specific. For critical separations it is prudent to maintain spare cartridges on-site.

Chemical sterilization may be performed after cleaning by circulating any of the following solutions

1. Up to 200 ppm sodium hypochlorite
2. Up to 3% formalin
3. Up to 0.5 N sodium hydroxide

The time for sterilization will depend on the process solution, the system design and the concentration of the sterilization chemical.

STORAGE

Cartridges should be thoroughly cleaned and rinsed with water prior to storage. Microfiltration cartridges may be stored dry. Ultrafiltration cartridges must be stored wet or re-glycerized.

For wet storage cartridges may be filled with storage solution and capped at all end fittings and permeate ports or submerged in a storage bath.

Acceptable Storage Solutions

1. Water with 5 to 10 ppm chlorine
2. 0.1 N NaOH
3. Up to 3% Formalin

Thoroughly flush all storage solution prior to reuse.

....

MEMBRALOX^R FILTRATION MODULE OPERATING INSTRUCTIONS

1. Prewetting Procedures

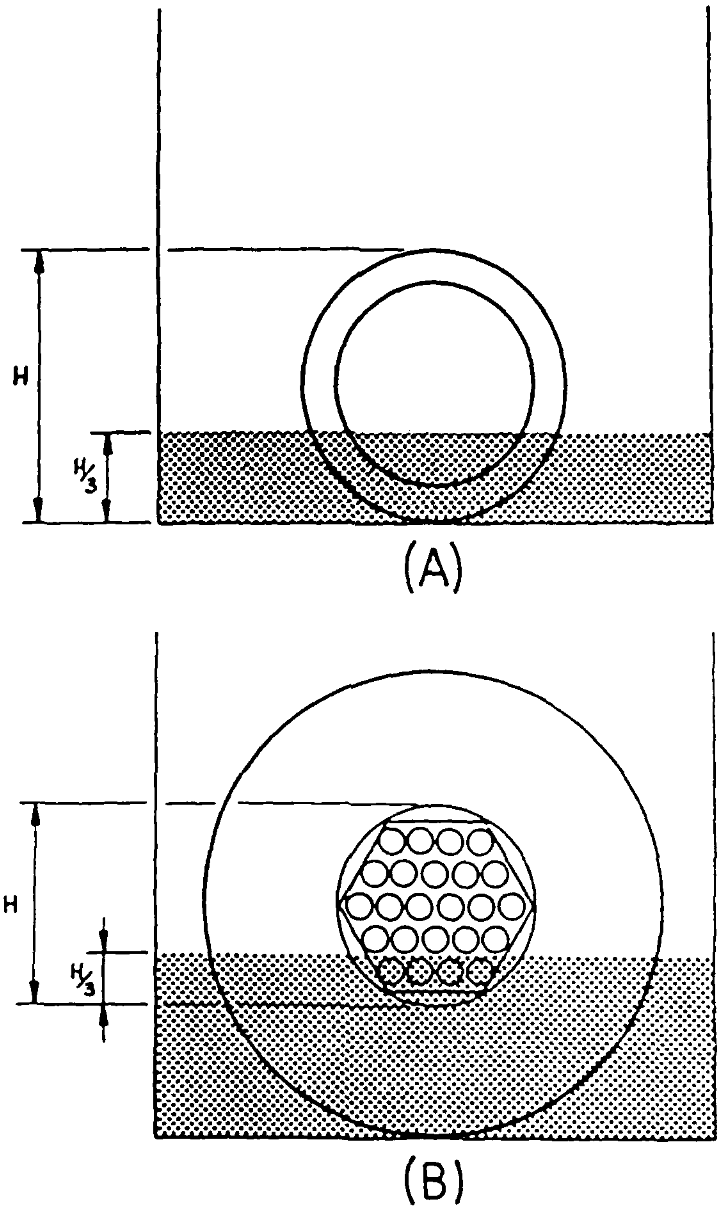
Permeate flux rates are significantly reduced if membrane wetting procedures are not carefully followed. The membrane must be thoroughly soaked before operation to prevent air pockets from forming in the membrane and reducing permeate flux rates. Normal operating pressures are not high enough to remove air pockets from a 0.2 micron pore size membrane.

In order to properly wet the ceramic tubes, place them in a trough of prefiltered water or permeate liquid. The height of the liquid should be approximately 1/3 the height of the tube (Fig. 1a). In the case of the 1P19-40 cartridge, the liquid level should be approximately 1/3 the height of the element, with the permeate port(s) facing up. Also, the shell should be filled to the same level as the surrounding solution (Fig. 1b).

Due to the capillary action, the liquid is drawn into the dry air filled membrane pores, thus, expelling the air and wetting the membrane completely and uniformly.

For 0.2 micron Membralox^R membranes, a minimum of 6 to 8 hours of soaking is necessary following the complete wetting of the multi-channel elements described above. For smaller pore-size membranes, a longer time will be required (usually 24 hours). However, it is recommended that whenever possible, allow longer durations for complete wetting (e.g., overnight). The extent of wetting may be determined visually, since wet elements are usually shiny and the surface is smooth and/or slippery to the touch. Subsequent clean water flux measurements with good reproducible results will further confirm the complete wetting of the membrane.

FIGURE 1



2. SOME IMPORTANT POINTS TO CONSIDER WHEN WORKING WITH ULTRA-FILTRATION CERAVER MEMBRANES (APPLICABLE TO BOTH 40 Å AND 500 Å PORE-SIZE MEMBRANES)

1. As a general measure of precaution, do not use aqueous NaOCl to clean the membranes as chlorine can react to destroy the γ-alumina membrane layer.

2. γ-alumina membranes are 3-5 μ thick. These layers are deposited on top of the γ-alumina support structures of varying pore size from 0.2 to 15 μ.

3. γ-alumina is not a stable equilibrium phase. Rather, it is a transitional phase in between the two stable equilibrium phases in which alumina exists as Boehmite or α.

4. It has limited chemical resistance and is susceptible to chemical attack when contacted with aqueous solutions above pH.

5. 40 Å membranes offer less resistance to chemical attack than the 500 Å membranes.

6. Temperatures above 60°C should not be used during the chemical cleaning as the decomposition of γ-alumina at pH above 9 or below 4 can be greatly accelerated.

7. Permeability may be pH dependent and can also be influenced by the presence of dissolved gases in solutions.

On the other hand, α-alumina is a stable material and offers good chemical resistance. It is quite stable in the pH range of 2-14. 100 to 200 ppm free chlorine does not attack α-alumina membranes. Thus, with 0.2 μ pore size (or higher) membranes, chemical cleaning with NaOCl solution (containing 100-200 ppm free chlorine) can be carried out.

3. GENERAL CLEANING METHOD

- Fill module (shell-side) with tap water.

- Close permeate valve.

- Start up system and run at a fast flush flow rate (~12 GPM).

- Run for 10, 15 or 20 minutes with either NaOH solution or NaOCl solution.

- Open permeate gradually during this time.

- Flush system with tap water for 10, 15 or 20 minutes gradually opening permeate valve.

- If HNO_3 is to be used also, it will now be run for 10, 15 or 20 minutes gradually opening permeate.

- A final water flush will be done for 10, 15 or 20 minutes.

> All runs done at pressures no higher than 10 psi. This is the maximum pressure achieved at a flow rate of 10 GPM.

> ΔP does not exceed 5 psi.

> pH of solutions is measured.

For cleaning 40 Å and 500 Å modules with aqueous NaOH solutions, pH must be maintained in the range 3-10 (preferably 4-9). However, for 0.2 μm and higher pore size Ceraver membranes, the cleaning procedure, as described below, can be modified:

- Washing with a NaOCl solution with 100 to 200 ppm free chlorine (the welds of the metal housing are the limiting factor for this concentration) : 10 min. at 20°C.

- Water rinse : 10 min. at >15°C.

- Washing with 2 wt% NaOH : 20 min. at 70°C (15 min. with a low ΔP, then 5 min. with ΔP = 1 bar).

- Water rinse : 10 min. at >15°C.

- Washing with 2 wt% HNO_3 : 20 min. at 70°C.

- Water rinse : 10 min. at >15°C.

Depending on the type of fouling matter, using the same cleaning fluids in a different order may give better results.

OPERATING INSTRUCTIONS FOR ENKA MICRODYN^R MODULES

1. The Enka Microdyn^R modules type MD 080 CS 2N and MD 080 TS 2N consist of a stainless steel housing with pipe connections, gaskets and one exchangeable cartridge.

   The types:
   MD 020 TP 2N

   MD 020 CP 2N

   MD 080 TP 2N

   MD 080 TP 2L

   MD 150 TP 2L

   MD 150 CP 2N
   have housing and membranes combined as one unit.

2. Wetting

   The microporous membranes are made of hydrophobic polypropylene (PP). Liquids with high surface tension e.g. water (72 dyn/cm) do not wet the membrane. Filtration of aqueous solutions requires, therefore, an activation of the membrane. This can be obtained by submerging the Enka Microdyn module for a few minutes in ethyl alcohol, isopropanol or any other liquid that has a surface tension below 35 dyn/cm and that is miscible with the liquid to be filtered.

   The module, after removing from the bath and drip-off of the excess wetting agent, is then installed in the filter system.

   Note: The wetting agent may not dry off prior to filtration!

   A renewed wetting is only necessary if the module has dried out or after working with vigorously degassing liquids (mineral water, beer). In the latter case the permeate should be kept under pressure to prevent degassing of the liquid.

3. Temperature

   The max. operating temperature is 40° and 60° respectively, depending on the type. Please consult the data sheet.

4. Operating Pressures

   The max. operating pressure can also be found in the data sheets.

5. Cleaning

In spite of applied periodic backwashing with permeate, depending on the product, an intensive cleaning with a cleaning agent may become necessary after periods of operation.

Those cleaning agents can be: Non-oxidizing acids or bases within a ph range of 0.5 to 14 e.g., hydrochloric acid, sulfuric acid, sodium hydroxide and others. Oxidizing cleaning agents may be used in low concentrations e.g., hydrogen peroxide, max. 5%. Organic solvents that don't swell polypropylene are also permissible.

Accurel[R] PP experiences heavy damage if it is exposed to strong oxidizing acids as nitric acid (10%) or concentrated sulfuric acid (10%) that lead to an oxidizing decay. Also sodium hydrochloride causes heavy damage on Accurel-PP

6. Negligence

Negligence of these instructions may lead to a reduced filter efficiency or a reduction in module life and therefore an elimination of Enka's warranty.

APPENDIX B-2

Sample Data Sheet

TTI ENGINEERING MEMBRANE SYSTEMS TESTING LABORATORY

PILOT-SCALE TEST SYSTEM DATA SHEET

Client ____________ Reference System No. ______ Test Operator ______ Sheet ____ of ____

Contract No. ____________ Test Date ______

TTI J.O. No. ______

Test Module Make & Model ____________ Feed Material Tested ____________

Feed Pump Make & Model ____________ Feed Tank Volume, L: Initial ______

Backpulse Pump Make & Model ____________ Final ______

TIME OF DAY	FEED			CONC.	PERMEATE		MECHANICAL CLEANING						
	Temp. °F	Flow, FI-1, gpm	Press., PI-1, psig	Press., PI-2, psig	Press., PI-3, psig	Flow, FI-2, gpm	Backpulse Press. PI-4, psig	Backpulse Press. PI-3, psig	Fast Flush ☐ or Rev. Flow ☐ Flow, FE-1	Press, PI-1	Press, PI-2	Period, Min.	Duration, Sec.

COMMENTS:

APPENDIX C

TEST DATA

PILOT SCALE MICROFILTRATION TEST SYSTEM — CLIENT: EGLIN AFB
TEST MODULE: ENKA #MD080TP2N, 0.2 micron — J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 10.76 — TEST DATE: 9/1/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
8:44	5.00	14.50	7.00	1.50	3.50	19.52	4.50
8:50	0.50	2.50	0.50	0.00	1.50	8.36	0.50
8:51	0.50	2.50	0.50	0.00	1.50	8.36	0.50
8:54	0.50	2.50	0.50	0.00	2.00	11.15	0.50
9:08	5.00	15.00	7.00	0.00	3.50	19.52	6.00
9:10	6.00	14.00	8.00	0.50	3.90	21.75	6.50
9:12	6.00	14.00	8.00	0.50	3.90	21.75	6.50

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	PERMEATE RECOVERY % RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.47	15.77	22.5	2.5	0.89		

Notes:
5 gallons of feed added at 9:05 for total of 22 gallons
Feed and concentrate ports were reversed for this test.

PILOT SCALE MICROFILTRATION TEST SYSTEM — CLIENT: EGLIN AFB

TEST MODULE: ENKA #MD080TP2N, 0.2 micron — J.O. NO.: 2019

EFFECTIVE FILTRATION AREA, sq ft: 10.76 — TEST DATE: 9/1/87

TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI

MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
8:44	5.00	14.50	7.00	1.50	3.50	19.52	4.50
8:50	0.50	2.50	0.50	0.00	1.50	8.36	0.50
8:51	0.50	2.50	0.50	0.00	1.50	8.36	0.50
8:54	0.50	2.50	0.50	0.00	2.00	11.15	0.50
9:08	5.00	15.00	7.00	0.00	3.50	19.52	6.00
9:10	6.00	14.00	8.00	0.50	3.90	21.75	6.50
9:12	6.00	14.00	8.00	0.50	3.90	21.75	6.50

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.47	15.77	22.5	2.5	0.89		

Notes:
5 gallons of feed added at 9:05 for total of 22 gallons
Feed and concentrate ports were reversed for this test.

PILOT SCALE MICROFILTRATION TEST SYSTEM CLIENT: EGLIN AFB
TEST MODULE: ENKA #MD080TP2N, 0.2 micron J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 10.76 TEST DATE: 9/2/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
2:58	5.00	14.00	7.00	0.50	1.55	8.64	5.50
3:02	10.00	14.00	11.00	1.80	3.11	17.34	8.70
3:03	15.00	13.20	16.50	2.50	4.54	25.32	13.25
3:05	20.00	12.50	21.00	4.50	5.43	30.28	16.00
3:06	25.00	12.00	25.00	6.00	6.38	35.58	19.00
3:07	30.00	11.50	30.00	8.50	7.32	40.82	21.50
3:09	35.00	11.20	35.00	10.00	9.68	53.98	25.00
3:11	40.00	10.70	40.00	12.00	9.68	53.98	28.00
3:12	40.00	10.70	40.00	14.00	9.16	51.08	26.00

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.23	35.22					

Notes:
Recirculating permeate to feed tank.
Permeate flow measured by accumulation over time.
Feed and concentrate ports were reversed for this test.

PILOT SCALE MICROFILTRATION TEST SYSTEM CLIENT: EGLIN AFB
TEST MODULE: ENKA #MD080TP2N, 0.2 micron J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 10.76 TEST DATE: 9/2/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
3:15	30.00	11.70	30.00	9.50	7.41	41.32	20.50
3:20	30.00	11.50	30.00	9.50	7.79	43.44	20.50
3:25	30.00	11.80	30.00	9.50	7.74	43.16	20.50
3:30	30.00	11.80	30.00	9.80	7.69	42.88	20.20
3:35	30.00	11.80	30.00	9.80	7.50	41.82	20.20
3:40	30.00	11.80	30.00	9.80	7.69	42.88	20.20
3:45	30.00	11.80	30.00	9.80	7.73	43.10	20.20
3:50	30.00	11.80	30.00	9.80	7.69	42.88	20.20
3:55	30.00	11.80	30.00	9.80	7.50	41.82	20.20

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.67	42.59					

Notes:
Recirculating permeate to feed tank.
Permeate flow measured by accumulation over time.
Feed and concentrate ports were reversed for this test.
Flux degrada.ion test.

PILOT SCALE MICROFILTRATION TEST SYSTEM CLIENT: EGLIN AFB
TEST MODULE: MEMBRALOX #1P19-40, 0.1 micron J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 2.10 TEST DATE: 9/2/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
8:57	0.00	5.00	3.00	0.00	0.30	8.57	1.50
8:58	5.00	3.00	6.00	0.00	1.10	31.43	5.50
9:02	5.00	3.00	6.00	0.00	1.20	34.29	5.50
9:06	20.00	6.50	20.00	2.00	2.20	62.86	18.00
9:10	5.00	10.00	10.00	0.00	1.90	54.29	7.50
9:12	8.50	13.00	16.00	0.00	2.80	80.00	12.25
9:13	15.00	12.50	22.00	1.50	3.90	111.43	17.00

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	PERMEATE RECOVERY INIT VOLUME	FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.27	54.69	19.5	3.00	0.85		

Notes:

Feed and concentrate ports were reversed for this test.

PILOT SCALE MICRCFILTRATION TEST SYSTEM　　CLIENT: EGLIN AFB
TEST MODULE: MEMBRALOX #1P19-40, 0.1 micron　　J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 2.10　　TEST DATE: 9/2/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
11:40	0.00	5.50	2.00	0.00	0.20	5.71	1.00
11:42	5.00	11.00	11.50	0.50	1.01	28.86	7.75
11:47	10.00	13.00	18.50	0.00	1.43	40.86	14.25
11:52	15.50	12.50	22.00	0.00	1.82	52.00	18.75
11:56	15.10	12.50	22.00	0.00	1.91	54.57	18.55
11:59	21.00	12.50	27.00	0.50	2.37	67.71	23.50
12:02	30.00	11.20	35.00	2.00	3.15	90.00	30.50
12:05	35.00	10.80	40.00	2.50	3.64	104.00	35.00
12:07	40.00	10.50	43.00	3.00	4.00	114.29	38.50
12:09	50.00	10.00	52.00	4.00	4.90	140.00	47.00
12:15	80.00	7.50	85.00	8.00	7.27	207.71	74.50

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.58	82.34					

Notes:

Feed and concentrate ports were reversed for this test.
Permeate flow rates were determined by accumulation over time.
Permeate was recycled back to the feed tank.

PILOT SCALE MICROFILTRATION TEST SYSTEM CLIENT: EGLIN AFB
TEST MODULE: MEMBRALOX #1P19-40, 0.1 micron J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 2.10 TEST DATE: 9/2/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
1:30	32.00	11.20	35.00	2.00	3.20	91.43	31.50
1:35	32.00	11.20	38.00	2.00	3.31	94.57	33.00
1:40	34.00	11.20	38.00	2.00	3.43	98.00	34.00
1:45	33.00	11.20	36.00	2.00	3.29	94.00	32.50
1:50	32.00	11.20	36.00	2.00	3.31	94.57	32.00
1:55	32.00	11.20	36.00	2.00	3.31	94.57	32.00
2:00	32.00	11.20	36.00	2.00	3.28	93.71	32.00
2:05	32.00	11.20	36.00	2.00	3.25	92.86	32.00
2:10	32.00	11.20	36.00	2.00	3.30	94.29	32.00
2:15	32.00	11.20	36.00	2.00	3.28	93.71	32.00
2:20	32.00	11.20	36.00	2.00	3.29	94.00	32.00
2:25	32.00	11.20	36.00	2.00	3.34	95.43	32.00

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
1.00	94.26					

Notes:

Feed and concentrate ports were reversed for this test.
Permeate flow rates were determined by accumulation over time.
Permeate was recycled back to the feed tank.
Gray powder-like substance was collected on the concentrate side
of the membrane module.
Flux degradation test.

PILOT SCALE MICROFILTRATION TEST SYSTEM CLIENT: EGLIN AFB
TEST MODULE: MEMBRALOX #1P19-40, 0.1 micron J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 2.10 TEST DATE: 9/3/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: BACKPULSE WITH FAST FLUSH FOR 2 SEC. EVERY 2 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
11:27	13.00	14.00	3.00	0.50	0.68	19.43	7.50
11:30	20.00	13.00	11.50	0.00	1.40	40.00	15.75
11:33	25.00	12.50	18.50	0.50	1.87	53.43	21.25
11:37	30.00	12.00	23.00	1.20	2.36	67.43	25.30
11:40	40.00	11.00	35.00	2.00	3.26	93.14	35.50
11:44	50.00	10.20	45.00	3.00	4.10	117.14	44.50
11:46	60.00	9.50	60.00	4.00	4.80	137.14	56.00
11:48	80.00	8.00	80.00	6.50	6.76	193.14	73.50
11:50	35.00	11.50	28.00	1.75	2.66	76.00	29.75
11:55	35.00	11.50	28.00	1.50	2.61	74.57	30.00
12:02	35.00	11.50	28.00	1.50	2.66	76.00	30.00

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.58	86.13					

Notes:

Repeat of R4 with feed and concentrate ports properly aligned.
Permeate flow rates were determined by accumulation over time.
Permeate was recycled back to the feed tank.
Gray powder-like substance was collected on the concentrate side of the membrane module.

AD-A195 655 FILTRATION SYSTEM FOR REMOVAL OF DEPLETED URANIUM FROM WATER(U) TII ENGINEERING NORWOOD MA L T FARRELL ET AL. FEB 88 AFATL-TR-87-66 F08635-87-C-0035 2/2

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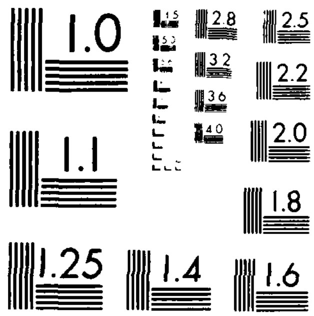

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

PILOT SCALE MICROFILTRATION TEST SYSTEM CLIENT: EGLIN AFB
TEST MODULE: A/G #CFP-1-E-55, 0.1 micron J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 23.00 TEST DATE: 9/1/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: REVERSE FLOW FOR 10 SEC. EVERY 10 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
11:35	0.00	5.00	1.00	0.00	2.70	7.04	0.50
11:38	1.00	7.50	2.00	0.00	3.40	8.87	1.50
11:40	1.50	10.00	3.50	2.00	2.40	6.26	0.50
11:43	0.00	7.50	1.50	0.00	3.20	8.35	0.75
11:44	0.00	7.50	1.50	0.00	3.30	8.61	0.75
11:45	5.00	13.00	8.50	3.50	2.90	7.57	3.25
11:46	8.50	13.00	5.00	3.50	2.90	7.57	3.25

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.18	7.75	19.5	1.50	0.92		

Notes:

Feed and concentrate ports were reversed for this run.

PILOT SCALE MICROFILTRATION TEST SYSTEM CLIENT: EGLIN AFB
TEST MODULE: A/G #CFP-1-E-55, 0.1 micron J.O. NO.: 2019
EFFECTIVE FILTRATION AREA, sq ft: 23.00 TEST DATE: 9/4/87
TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI
MECHANICAL CLEANING: REVERSE FLOW FOR 10 SEC. EVERY 10 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
10.10	21.00	13.00	17.50	6.00	6.25	16.30	13.25
10:15	21.00	13.00	18.00	6.00	6.25	16.30	13.50
10:20	20.00	13.00	18.00	6.00	6.19	16.15	13.00
10:30	22.00	13.00	18.00	6.00	6.19	16.15	14.00
10:35	21.50	13.00	18.00	6.00	6.35	16.57	13.75
10:40	22.00	13.00	18.00	6.00	6.28	16.38	14.00
10:45	20.50	13.00	18.50	6.00	6.22	16.23	13.50
10:50	21.00	13.00	18.80	6.00	6.59	17.19	13.90
10:56	22.00	13.00	18.80	6.00	6.35	16.57	14.40
11:02	22.00	13.00	17.50	6.00	6.45	16.83	13.75
11:05	20.50	13.00	17.50	6.00	6.45	16.83	13.00
11:10	20.00	13.00	18.00	6.00	6.15	16.04	13.00

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	% RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.83	16.46					

Notes:

Permeate flow rates were determined by accumulation over time.
Permeate was recycled back to feed tank.
Flux degradation test.

PILOT SCALE MICROFILTRATION TEST SYSTEM — CLIENT: EGLIN AFB

TEST MODULE: A/G #CFP-1-E-55, 0.1 micron — J.O. NO.: 2019

EFFECTIVE FILTRATION AREA, sq ft: 23.00 — TEST DATE: 9/4/87

TEST MEDIUM AND SOURCE: DU-OXIDE IN WATER PREPARED BY NMI

MECHANICAL CLEANING: REVERSE FLOW FOR 10 SEC. EVERY 10 MIN.

TIME OF DAY	FEED PRESSURE psig	FEED FLOWRATE gpm	CONCENTRATE PRESSURE psig	PERMEATE PRESSURE psig	PERMEATE FLOWRATE gpm	PERMEATE FLUX gal/sqft/hr	TRANSMEMBRANE PRESSURE DROP psig
8:05	7.00	15.00	0.00	2.00	2.87	7.49	1.50
8:10	7.50	14.70	3.50	2.00	2.88	7.51	3.50
8:20	10.00	14.50	6.00	2.50	3.60	9.39	5.50
8:31	15.00	13.70	11.50	4.20	4.87	12.70	9.05
8:37	20.00	13.00	17.80	6.00	6.00	15.65	12.90
8:50	25.00	12.50	22.00	7.50	7.14	18.63	16.00
8:53	30.00	30.00	28.00	9.00	8.00	20.87	20.00
8:57	36.00	36.00	35.00	7.50	7.69	20.06	28.00

TOTALS FOR TEST PERIOD:

TEST TIME (hrs)	AVERAGE PERMEATE FLUX (gal/sqft/hr)	INIT VOLUME	PERMEATE RECOVERY FINAL VOLUME	PERMEATE RECOVERY % RECOVERY	INIT SOLIDS WT. %	FINAL SOLIDS WT. %
0.87	14.04					

Notes:

Permeate flow rates were determined by accumulation over time.
Permeate recycled back to the feed tank.

APPENDIX D

CHEMICAL ANALYSES RESULTS

CHEMICAL ANALYSIS BY CAROLINA METALS, INC. (CMI)

SUMMARY OF DATA

SAMPLE	PPM*	PICO-CURIES CC	PPM**	PICO-CURIES CC	PPM***	PICO-CURIES CC
ENKA CONC.	11.9	4.3	7.1	2.6	12.0	4.3
ENKA FEED	12.6	4.5	4.2	1.5	13.7	4.9
ENKA PERMEATE	11.4	4.1	6.1	2.2	11.5	4.1
ALCOA CONC.	6.9	2.5	2.3	0.8	15.8	5.7
ALCOA FEED	6.5	2.3	2.6	0.9	10.7	3.9
ALCOA PERMEATE	6.1	2.2	3.3	1.2	7.4	2.6
A/G CONC.	13.0	4.7	0.9	0.3	28.4	10.2
A/G FEED	12.9	4.6	4.3	1.5	16.2	5.8
A/G PERMEATE	11.5	4.1	1.7	0.6	12.6	4.5

Method: Inductively Coupled Plasma Spectroscopy
For convenience, values are also expressed in picocuries per cc.

* 100 ml. of stock solution concentrated 10X in 10% nitric acid.

** 100 ml. of stock solution concentrated 10X in water.

*** 100 ml. of stock solution concentrated 10X in 10% nitric acid <u>after</u> washing walls of each sample container with nitric acid in accordance with procedure used by Eglin Air Force Base.

CHEMICAL ANALYSIS BY NUCLEAR METALS, INC. (NMI)

SUMMARY OF DATA

SAMPLE	CMI (PPM)	NMI GAMMA (PPM)	NMI ALPHA (PPM)
A/G FEED	12.9	13.1	17.5
A/G PERMEATE	11.5	6.35	9.62
A/G CONC.	13.0	24.3	27.3
ALCOA FEED	6.5	8.62	9.8
ALCOA PERMEATE	6.1	3.54	5.25
ALCOA CONC.	6.9	14.7	14.3
ENKA FEED	12.6	5.43	6.25
ENKA PERMEATE	11.4	10.5	10.0
ENKA CONC.	11.9	6.05	8.8

RADIOACTIVE SOLIDS CONTENT ANALYSIS

SUMMARY OF DATA

Sample	EGLIN ppm[1]	EGLIN pCi/cc	NMI ppm[1,2]	NMI pCi/cc	CMI ppm[1]	CMI pCi/cc
ENKA Conc.	12.4	4.47	6.05 8.8	2.18 3.17	12.0	4.3
ALCOA Conc.	14.2	6.10	14.7 14.3	5.29 5.18	15.8	5.7
A/G Conc.	54.1	19.46	24.3 27.3	8.75 9.83	28.4	10.2
ENKA Feed	27.7	9.97	5.43 6.25	1.95 2.25	13.7	4.9
ALCOA Feed	17.4	6.26	8.62 9.8	3.10 3.83	10.7	3.9
A/G Feed	26.5	9.55	13.1 17.5	4.72 6.30	16.2	5.8
ENKA Permeate	20.3	7.31	10.5 10.0	3.78 3.6	11.5	4.1
ALCOA Permeate	11.4	4.09	3.54 5.25	1.27 1.89	7.4	2.6
A/G Permeate	17.4	6.26	6.35 9.62	2.29 3.46	12.6	4.5

[1] Solids concentration in ppm calculated from radiation level by count, based on U_3O_8 being prevalent solid in sample analyzed.

[2] First entry is gamma result; second entry is alpha result.

DAT

ILM